

無線網路多媒體系統 Wireless Multimedia System

Radio Propagation: Issues & Models

Dr. Eric Hsiaokuang Wu
<http://inrg.csie.ntu.edu.tw>



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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

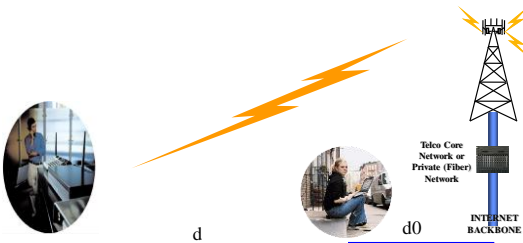


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Path Loss Model (Large Scale)

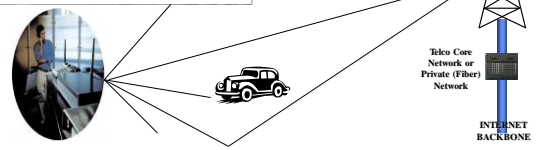
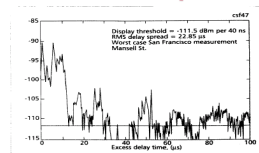
$$\overline{PL}(d) = \overline{PL}(d_0) + 10n \log\left(\frac{d}{d_0}\right)$$



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Multi-path fading (Small Scale)



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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"

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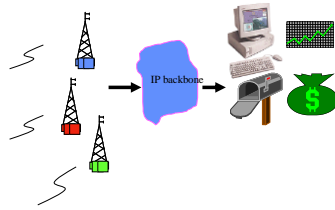
The mystery of the Radio Propagation



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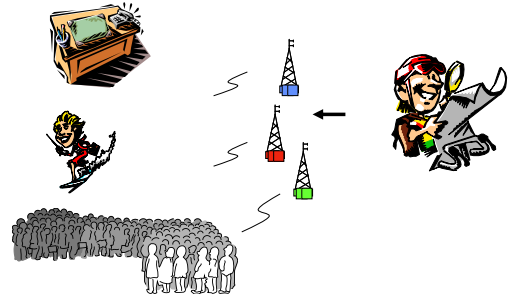
How to deal with Radio Propagation



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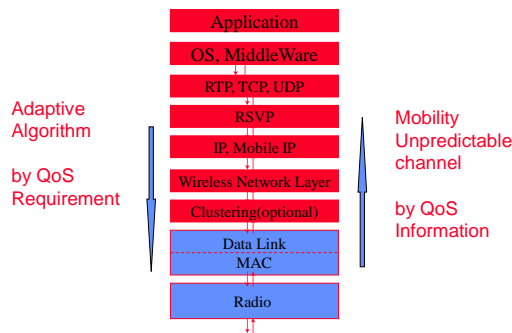
Where are you from?



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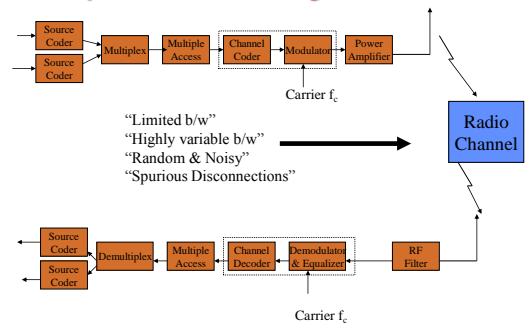
QoS and Multimedia Traffic Support



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Simplified View of a Digital Radio Link



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Digital to Analog Modulation

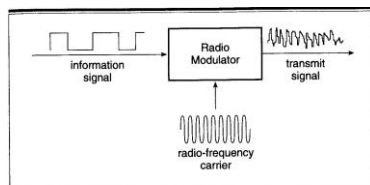


Figure 6.2 Single-stage digital modulation (TDMA and FDMA).

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Digital-Digital-Analog Modulation

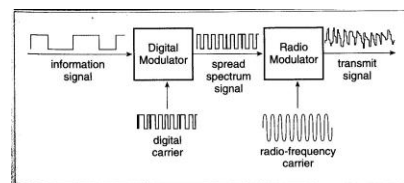


Figure 6.3 Two stages of modulation in a spread spectrum system.

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Digital Correlator

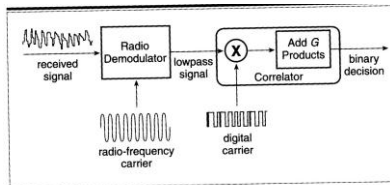


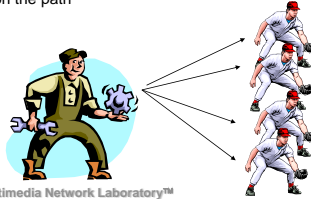
Figure 6.4 Two stages of demodulation in a spread spectrum receiver.



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



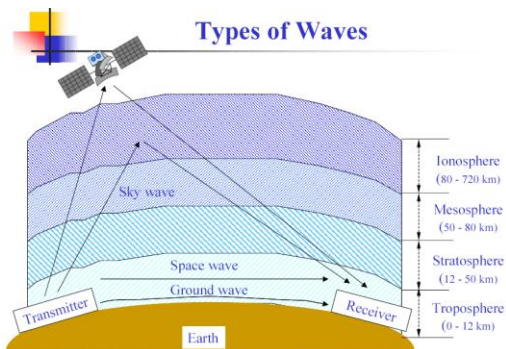
$$\text{Light speed} = \text{Wavelength} \times \text{Frequency}$$

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

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



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



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Some Distributions



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



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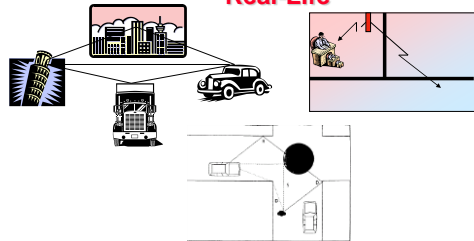


Propagation Mechanisms in Space with Objects



- ♦ 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

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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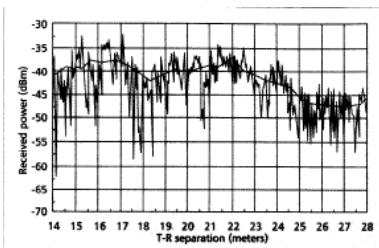
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Small-scale and Large-scale Fading



- ♦ 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.,

$$L = L_p L_S L_F$$

\uparrow Fast fading
 \uparrow Slow fading
 \uparrow Path loss

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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:

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

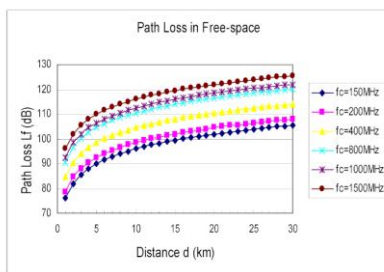
where f_c is the carrier frequency.

This shows greater the f_c , more is the loss.

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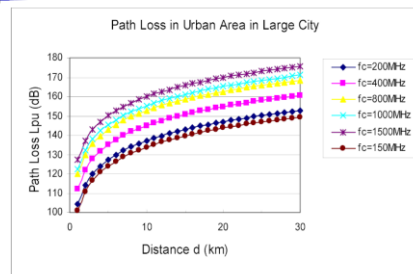
Example of Path Loss (Free-space)



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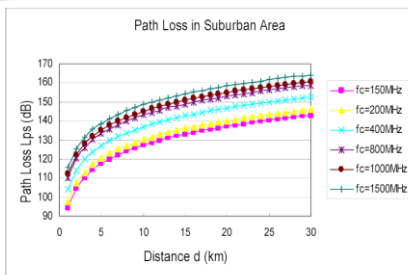
Example of Path Loss (Urban Area: Large City)



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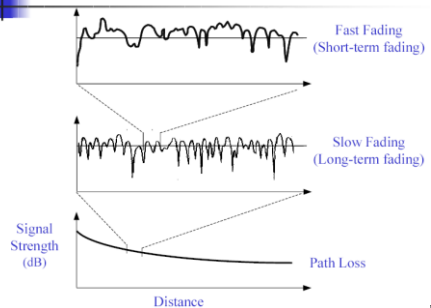
Example of Path Loss (Suburban Area)



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Fading



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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



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Large Scale -> Link Budget



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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

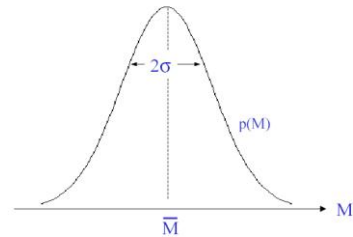
$$p(M) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(M-\bar{M})^2}{2\sigma^2}},$$

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 ,
 σ is the standard deviation in decibels

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Log-normal Distribution



The pdf of the received signal level

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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

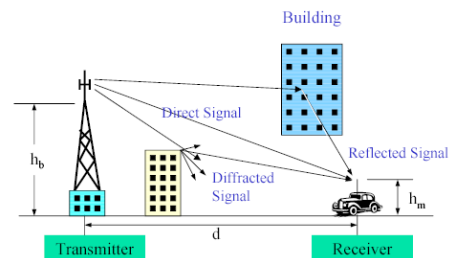
$$PL(dB) = 10 \log \frac{P_t}{P_r}$$

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

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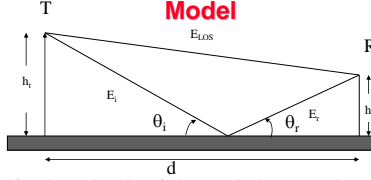
Radio Propagation Effects



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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

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

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

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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)

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

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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

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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



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

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

$$N = kT_b BF$$

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

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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:

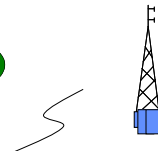
- $N = -174 \text{ dBm} + 10 \log 30000 + 10 \text{ dB}$
- For $SNR > 25 \text{ dB}$, we must have $Pr > (-119+25) = -94 \text{ dBm}$
- $P_t = 0.6W = 27.78 \text{ dBm}$
- This allows path loss $PL(d) = P_t - Pr < 122 \text{ dB}$ for free space, $n=2$, $d < 33.5 \text{ km}$ for shadowed urban with $n=4$, $d < 5.8 \text{ km}$

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Link Budget (SNR)

- Frequency
- Power
- Distance
- Environments
- Bandwidth

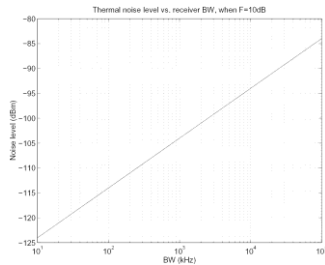


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Noise

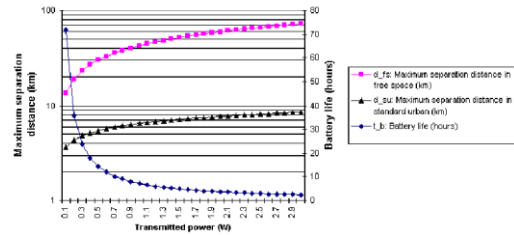
- $N = kT_b B F$ ($k = 1.38 \times 10^{-23} \text{ J/K}$ Boltzmann's constant, $T_b = 290 \text{ K}$)
- $N(\text{dBm}) = 174(\text{dBm}) + 10 \log_{10} B + F(\text{dB})$



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Distance/Power/Battery/Environment

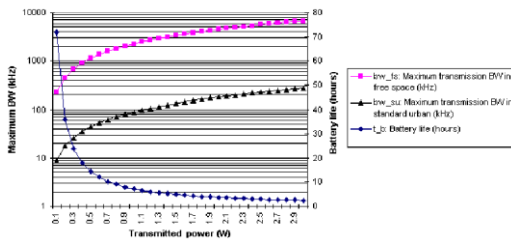
Combined plot of the maximum separation distance and the battery life vs. transmitted power, when $BW = 30 \text{ kHz}$, $F = 10 \text{ dB}$, $\text{SNR} = 25 \text{ dB}$.



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BW/Power/Battery/Environment

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



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Effectiveness of RTS/CTS handshake in 802.11 Ad hoc Network

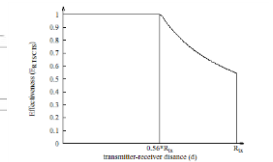
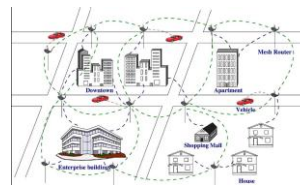


Fig. 2. Effectiveness of RTS/CTS handshake for TWO-RAY GROUND model and SNR threshold as 10.

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Large Area Interference Problem

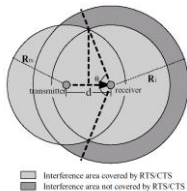


Fig. 1. Effectiveness of RTS/CTS handshake when d is larg $T_{RTS} + T_{CTS} \leq R_{tx}$ and smaller than R_{rx} .

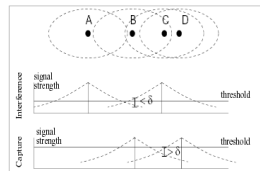


Figure 2: Interference and Capture

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RMS Delay Spreads

TYPICAL RMS DELAY SPREADS IN VARIOUS ENVIRONMENTS.

Environment	Freq. (MHz)	σ_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	70-04	Average	[27]
Indoor - Office Buildings	1900	1470	Maximum	[27]

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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

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

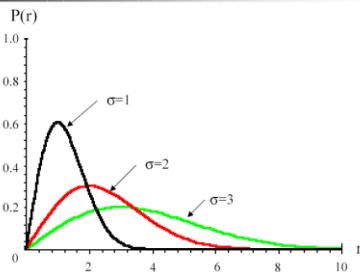
where σ is the standard deviation.

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

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

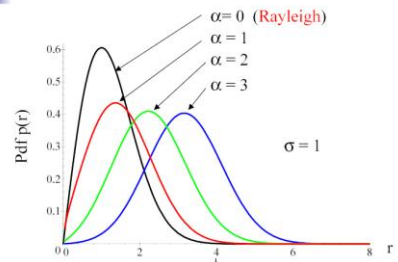
- We have $r_m = 1.777 \cdot \sigma$

Rayleigh Distribution



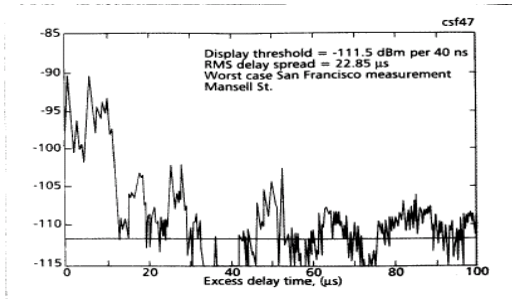
The pdf of the envelope variation

Rician Distribution



The pdf of the envelope variation

Delay Spread



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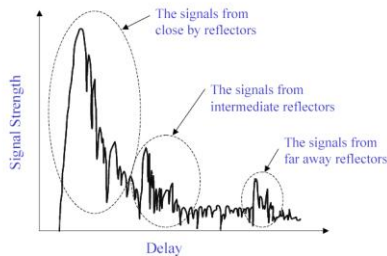
Delay Spread

- 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)

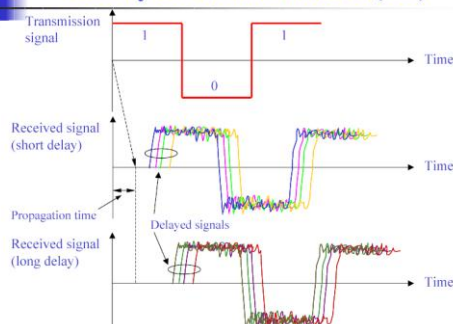
$$R < \frac{1}{2\tau_d}$$

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

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Intersymbol Interference (ISI)



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Coherence Bandwidth

- 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

- ♦ 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

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

- Coherence bandwidth

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

- Doppler spread

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

- Coherence time

$$T_c = 0.423 / f_m$$

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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,

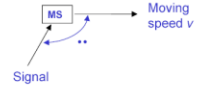
f_D is the Doppler frequency.

- ♦ **Doppler Shift in frequency:**

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

where v is the moving speed,

λ is the wavelength of carrier.



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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

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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.

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The Design of Wireless Modem



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Combating Errors

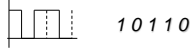
- ♦ Increase transmitted power
- ♦ (Adaptive) Equalization
- ♦ Antenna or space diversity for "Multipath"
- ♦ Forward error correction
- ♦ Automatic Repeat Request (ARQ)

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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:

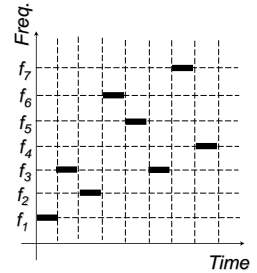


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Frequency Hopping Spread Spectrum

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



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Antenna Types



■ Omni Directional Antenna



◆ YAGI Directional Antenna

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Modern Applications: 911 Service



Location Service

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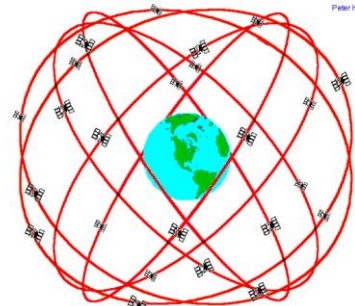


E-911 Requirement for Location Service

- 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



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GPS Nominal Constellation

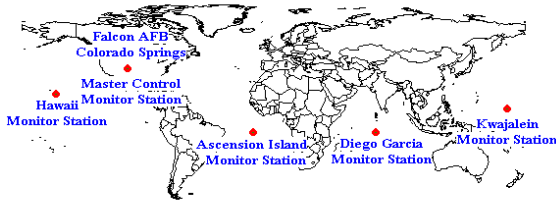
24 Satellites in 6 Orbital Planes

4 Satellites in each Plane

20,200 km Altitudes, 55 Degree Inclination

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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.

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.

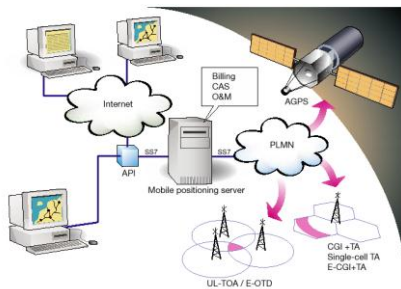
Positioning mechanism and requirement

Terminal-based :

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

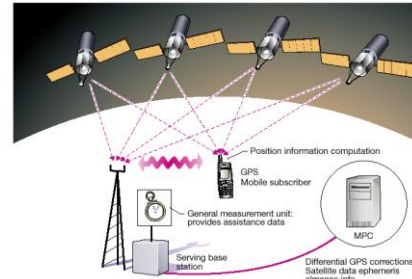
Network-based :

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



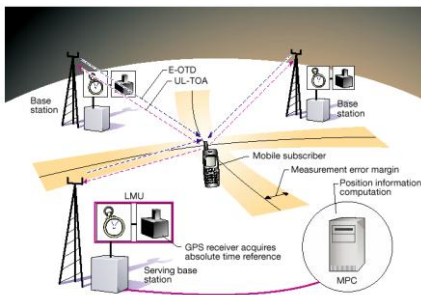
Mobile location solution has been designed to handle a variety of positioning methods and application interfaces.

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

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

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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).

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Location applications (cont.)

Resource management :

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

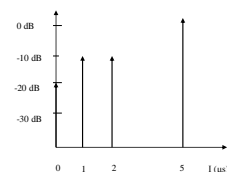
Navigation :

- Vehicle or pedestrian navigation.

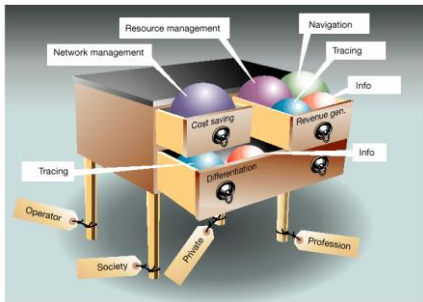
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Small Scale Fading

- Mean Excess Delay, rms delay spread



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

Channel Propagation and Fading

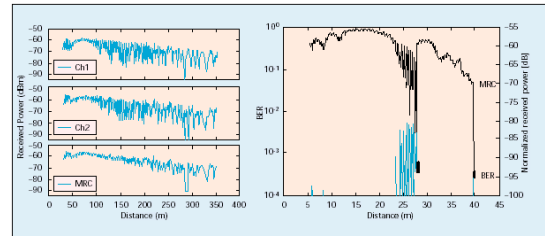


Figure 4. Received power as a function of distance: in a street (left), in a pavilion (right), BER and handover (right).