King Fahd University of Petroleum & Minerals
Computer Engineering Dept

COE 543 – Mobile and Wireless Networks

Term 022

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Lecture Contents

1.

RF propagation

- Free Space: $$\frac{P_r}{P_t} = G_t G_r \times \left(\frac{\lambda}{4\pi d}\right)^2$$
- Two-Ray Model: $$\frac{P_r}{P_t} = G_t G_r \times \left(\frac{h_b h_m}{d^2}\right)^2$$

(one line-of-sight ray and the other is ground reflected wave)

- General Power-Distance relation: $P_r = P_0 d^{-\alpha}$
- Range for α with respect to different environments

RF propagation - Shadowing

- Zero-mean normal r.v:

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma_{dB}} \exp\left(\frac{-x^2}{2\sigma_{dB}^2}\right)$$

- σ_{dB} is a function of the propagation environment – typical value ~ 8 dB
- Fade Margin (F_σ): When computing signal coverage a margin of power dBs are added to compensate for the slow fading parameter

RF propagation – Shadowing (2)

- **Problem**: For a Gaussian variable X with mean m and standard deviation of s, what is the probability that X exceeds F?
- **Solution**:

$$\text{Prob}[X > F] = \text{Prob}[\,(X-m)/\sigma > (F-m)/\sigma]$$
$$= \text{Prob}[X_\sigma > F_\sigma]$$

where X_σ is the zero-mean Gaussian r.v. with unity standard deviation.

$$\Pr[X_\sigma > F_\sigma] = \frac{1}{\sqrt{2\pi}} \int_{F_\sigma}^{\infty} e^{-t^2/2}\, dt$$ which is tabulated as $Q(F_\sigma)$

One can also use the erfc as well: since erfc is defined as

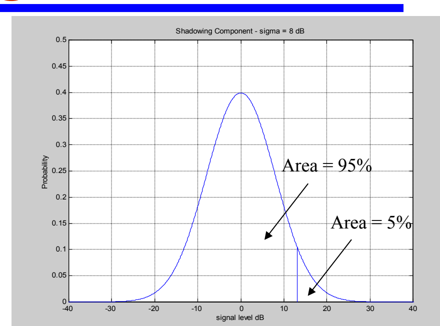
$$erfc(x) = \frac{2}{\sqrt{\pi}} \int_x^{\infty} e^{-t^2}\, dt$$

therefore, $Q(F_\sigma) = 0.5 X erfc(F_\sigma/\text{sqrt}(2))$,

Example: Fade Margin Calculation

- Solution:

Let the local mean = M,
Therefore, the overall signal level,
S = M + X
where X is a normal r.v. specifying the shadowing process (i.e. X ~ N(0, σ=8 dB))
Note that Prob[S< M] = Prob[S>M] = 0.5
It is desired to add a fade margin F such that
Prob[M-X+F>M] = 0.95, or
Prob[X > F] = 0.05, or
Prob[X/σ > F/σ] = 0.05
→ 0.05 = 0.5 erfc((F/σ)/sqrt(2))
→ F/σ = 1.163Xsqrt(2)
→ F = 13.16 dB



RF propagation Models

Okumura-Hata (Macrocellular)	d < 20 km f_c < 1500 kHz
COST-231 (Macrocellular)	PCS range (f_c =1800 – 2000 MHz)
JTC (Macrocellular)	PCS range f_c ~ 1800 MHz
Microcellular	100 m ~ few kilometers $d_{bk} = 4h_b h_m/(1000)$ km $\Delta H = h_b$ – avg building height Δh_m = avg building height – h_m
Picocellular (indoor)	$L_p = L_0 + nF + 10\alpha\log(d)$ 30 m ~ 100 m Takes # of floors into account
ITC Picocellular (indoor)	$L_p = L_0 + L_{f(}n) + 10\alpha\log(d)$
Femtocellular (indoor)	$L_p = L_0 + 10\alpha\log(d)$ d = 2 ~ 10's m

Short Term (Rayleigh) Fading

- For $2P_0$ is the mean power received at the mobile, the distribution of the received signal *envelope* (random variable because of multipath) r is given by

$$f(r) = \frac{r}{P_0}\exp\left(\frac{-r^2}{2P_0}\right)$$

- The instantaneous power, r^2, is distributed as in

$$f(p) = \frac{1}{2P_0}\exp\left(\frac{-p}{2P_0}\right)$$

where the mean received power is $2P_0$

Doppler Effect

- Explain the Doppler effect?

$$f_d = f_m \times \cos(\theta) = \frac{v\cos(\theta)}{\lambda} = \frac{v_{eff}}{\lambda} = \frac{v_{eff} \times f_c}{c}$$

where $f_m = v/\lambda$ = maximum value of Doppler

v_{eff} is the effective velocity

f_c is the carrier frequency

θ is the path angle

- Instantaneous Doppler
- Maximum Doppler
- Doppler Distribution

Delay Spread

- Explain the delay spread cause?
- How does it effect the communication system?
- RMS delay spread – How to compute? And what is its indication?
- Typical RMS values for different environments?
- Coherence bandwidth – how is it related to delay spread?

Mitigation Methods

Issue	Performance Affected	Mitigation Techniques
Shadow fading	Received signal strength	Fade margin – Increase transmit power or decrease cell size
Fast fading	Bit error rate	Error control coding
	Packet error rate	Interleaving, Frequency hopping, Diversity
Multipath delay spread	ISI and irreducible error rates	Equalization, DS-spread spectrum, OFDM, Directional antennas

Example 1:

- **Problem 2.8 [Pahlavan]**: The modulation technique used in the existing AMPS is analog FM. The transmission bandwidth is 30 kHz per channel and the maximum transmitted power from a mobile use is 3 W. The acceptable quality of the input SNR is 18 dB, and the background noise in the bandwidth of the system is -120 dBm (120 dB below the 1mW reference power). In the cellular operation we may assume the strength of the signal drops 30 dB for the first meter of distance from the transmitter antenna and 40 dB per decade of distance for distances beyond 1 meter.
  a. What is the maximum distance between the mobile station and the base station at which we have an acceptable quality of signal?
  b. Repeat (a) for digital cellular systems for which the acceptable SNR is 14 dB

Example 1: cont'd

- **Solution:**

(a) Maximum distance for an SNR of 18 dB.

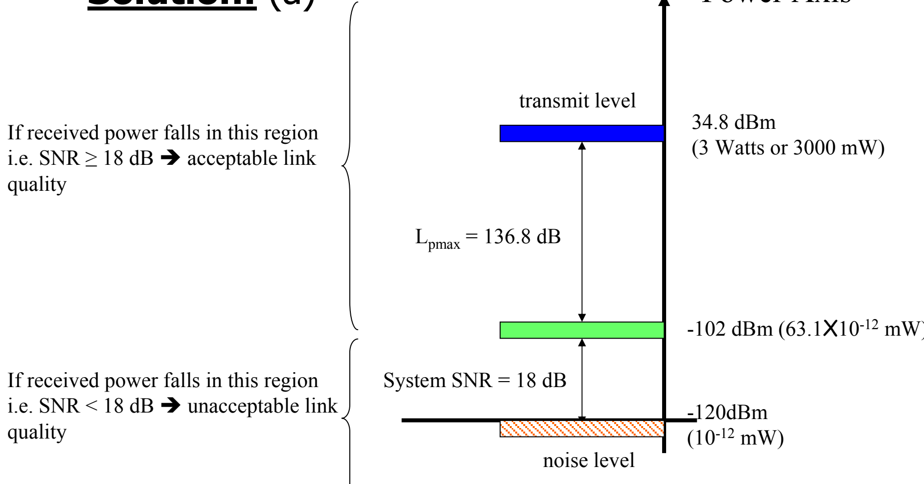
- The transmitter power is $P_t = 10\log(3\,W/1\,mW) =$ 34.8 dBm
- The minimum acceptable received power is P_{rmin} = -120 dBm + 18 dB = -102 dBm
- The maximum allowable path loss is $L_{p\max} = P_t - P_{r\min}$ = 34.8 dBm - (-102 dBm) = 136.8 dB
- The path loss model based on 30 dB in the first meter and 40 dB per decade of distance is

$$L_p = 30 + 40\log(d) \quad \text{so that} \quad d = 10^{\frac{L_p - 30}{40}} \quad \text{and}$$

$$d_{\max} = 10^{\frac{L_{pmx} - 30}{40}} = 10^{\frac{136.8 - 30}{40}} = 468 \text{ m}$$

Example 1: cont'd

- **Solution:** (a)



Example 1: cont'd

- **Solution:**

(b) Maximum distance for an SNR of 14 dB.

- The transmitter power is $P_t = 10\log(3\,W/1\,mW) =$ 34.8 dBm
- The minimum acceptable received power is P_{rmin} = -120 dBm + 14 dB = -106 dBm
- The maximum allowable path loss is $L_{p\max} = P_t - P_{r\min}$ = 34.8 dBm - (-106 dBm) = 140.8 dB
- The path loss model based on 30 dB in the first meter and 40 dB per decade of distance is

$$L_p = 30 + 40\log(d) \quad \text{so that} \quad d = 10^{\frac{L_p - 30}{40}} \quad \text{and}$$

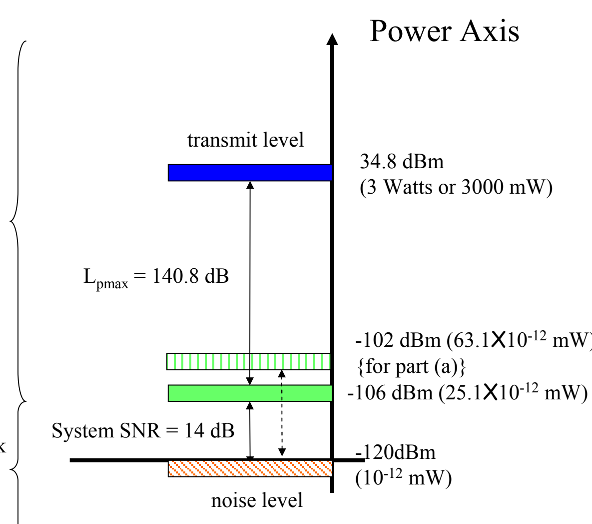
$$d_{\max} = 10^{\frac{L_{pmx}-30}{40}} = 10^{\frac{140.8-30}{40}} = 589 \text{ m}$$

Example 1: cont'd

- **Solution:** (b)

If received power falls in this region i.e. SNR ≥ 14 dB ➔ acceptable link quality

If received power falls in this region i.e. SNR < 14 dB ➔ unacceptable link quality



Cellular Concept

- Why do we do frequency reuse?
- Reuse distance relation with cell radius:

$$D = \sqrt{3N}R \qquad N = i^2 + j^2 + ij \qquad i, j = 0,1,2,3,\ldots$$

- Downlink SIR considering 1st tier and using omni-direction antennas: $\frac{S}{I} = \frac{1}{\sum_{k=1}^{6} (q)^{-\alpha}} = \frac{q^\alpha}{6}$
- How would it looklike for sectorized antennas?

Capacity Expansion Techniques

- Use of Directional Antennas (refer to previous slides)
- Cell Splitting
- Lee's Mircocell Method
- Overlaid Cells
- Use of Smart Antennas

Problem 5.4

- **Problem**: We have an installed cellular system with 100 sites, a frequency reuse factor of N = 12 and 500 overall two-channels:
  - a) Give the # of channels per cell, total # of channels available to the service provider, and the minimum carrier-to-interference (C/I) of the system in dB
  - b) To expand the network we decide to create an underlay-overly system where the new system uses a frequency reuse of K = 3. Give the number of channels assigned to inner and outer cells to keep a uniform density traffic over the entire coverage area

Problem 5.4 – cont'd

- **Solution**:

a) # of channels per cell = 500 / 12 = 41

Total # of channels available for provider = 41X100

= 4100 channels

Minimum C/I for K = 12:

SIR or CIR = $q^4/6$

= [sqrt(3X12)]4/6

= 216

= 23.3 dB

Problem 5.4 – cont'd

- **Solution**:

b) Underlay network with K = 12 – overlay network with K = 3

D_0/R_0 = sqrt(3X12) = 6 = D_1/R_1

D_1 = 3XR_0 (see figure)

➔ $3R_0/R_1 = 6$ or $R_0 = 2XR_1$

$A_0 = 4XA_1$, or $A_1 = 0.25\ A_0$

If N is # of total channels

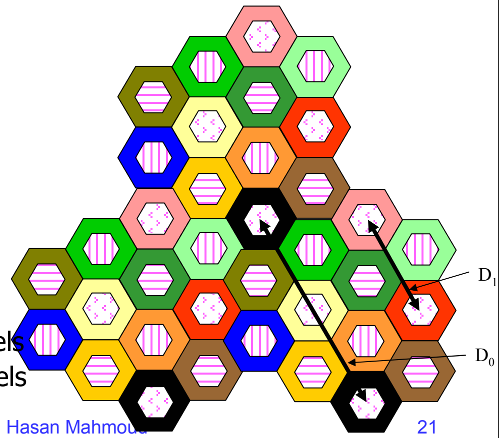
3(0.25N)+12(0.75N) = 500

➔ N = 51.3

Therefore,

For inner cells: 0.25N = 12 channels

For outer cells: 0.75N = 38 channels



TDMA Capacity

- **Problem** Consider the following parameters for the following 2nd generation IS-54 network:

  - Total BW = 1.25 MHz (for uplink – another 1.25 is allocated for the downlink)
  - Required SIR for proper operation = 18 dB
  - Path loss exponent = 4
  - No of antenna sectors at the cell sites = 3
  - Carrier spacing = 30 kHz
  - TDMA frame = 3 slots per carrier

  a) Compute the maximum number of voice channels per sector provided by such network.

  b) If a typical mobile subscriber attempts a call every 2 two hours with a mean call holding time of 3 minutes, how many subscribers in a cell area can be accommodated for a blocking rate of 2%. Use the attached Erlang-B curves for offered traffic versus blocking rate for different values of c.

  c) Calculate the network efficiency interms of carried erlangs / Hz

TDMA Capacity

- **Solution**

a) We know that SIR = $1/(SXq^{\alpha})$ and q = sqrt(3K) ➔ K = 1/3 X $[6/S \text{ X } SIR]^{2/\alpha}$

For SIR = 18 dB or 63.1, S = 3, K = 3.7 ~ 4

1.25 MHz ➔ 1.25X1000/30 = 41.6 carrier / cell

41.6 / 3 sectors = 13.8 carrier / sector

No of voice channels per sector = 13.8 X 3

= 41.6

b) λ_i = 1 / 120 call/minutes, $1/\mu$ = 3 min/call

Traffic offered per subscriber (ρ_i) = λ_i/μ =0.025 Erlangs

The overall offered traffic = ρ_{total} = No of subs X ρ_i

For 2% blocking at the SECTOR with c = 41 ➔ Offered load (from tables) = 31.9 Erlangs

➔ No of subs = 31.9/0.025 = 1276 sub / sector, or

➔ No of subs = 1276 X 3 = 3828 subs / cell

➔ No of subs = 3828 X 4 = 15312 subs for the 1.25 MHz

TDMA Capacity

- **Solution**

c) Carrier traffic per sector = 31.9 X (1-2%)

= 31.3 Erlangs

➔ Carrier traffic per network = 31.3XSXK

= 375.1 Erlangs

Efficiency = 375.1 Erlangs / 1.25 MHz

= 0.3 Erlagns/Hz