ECSE-6961: Fundamentals of Wireless Broadband Networks
Spring 2007, Exam 1
SOLUTIONS

Time: **75 min (strictly enforced)**

Points: **50**

YOUR NAME:

Be brief, but DO NOT omit necessary detail

{Note: Simply copying text directly from the slides or notes will not earn (partial) credit. Brief, clear and consistent explanation will.}

I. [4 pts] Wireless Technologies

Compare and contrast UWB and Wimax technologies (use a couple of similarities and differences to make your case).

UWB : 1) Communication occupies 500 MHz or higher spectrum

2) Lies in the 3.6 -10.1 GHz range

3) It is like an impulse radio, sends pulses every tens of picoseconds. This consumes lot of bandwidth due to low duty cycle.

4) It has excellent ranging capabilities.

5) Multipath is highly resolvable

6) Typically high data rate, low range and moderate power dissipation

Wimax : 1) Also lies in 2 – 11 GHz spectrum like UWB.

2) channel bandwidths are 1.75 MHz or its multiples unlike UWB

3) Uses only OFDM-PHY and MIMO capabilities.

4) Higher power dissipations, lower data rates.

II. [6 pts] <u>Wireless Concepts</u>

Briefly explain

a) What are OFDM, CDMA and MIMO? Why are these concepts important in wireless broadband communications?

b) How is the effect of interference different from the effect of fading on system performance? What methods can be used to mitigate interference?

A) ***OFDM*** – Orthogonal Frequency division multiplexing. Take inverse Fourier transform of signals in frequency domain, add cyclic prefix and at receiver take Fourier transform to get back the signal. Thus avoiding interference within an OFDM symbol by maintaining orthogonality. ***CDMA*** – Code division multiple access. Each mobile subscriber is assigned a unique code using pseudo random number generator and hence can use the entire CDMA frequency band and time (No explicit TDMA or FDMA) for communication unlike GSM. ***MIMO*** – Multiple Input multiple output Technique (spatial multiplexing technique) of using multiple antennas at Tx/Rx for better SINR and to reduce BER. Since the wireless medium is inherently shared, these concepts are important to efficiently utilize the shared resource and to boost the system spectrum efficiency.

B) Interference is caused by interfering signals transmitted from other transmitters. Fading is the natural attenuation of electromagnetic waves (due to refraction, reflection etc). Interference can have severe effects on system performance (SINR) particularly destructive interference. To mitigate interference : (i) Operate within critical distance so that interference power is less. (ii) CDMA mitigates interference by maintaining othrogonality between codes allocated to different users. (iii) OFDM to decrease self interference (iv) power regulation (v) frequency reuse etc.

III. [6 pts] Small Scale Fading:

1. What is flat fading and how is it different from AWGN & large-scale path loss? Why is Rayleigh/Ricean a good statistical model for flat fading?
2. How exactly does multi-path fading lead to frequency-selectivity and ISI in a broadband channel?
3. How exactly does mobility lead to time-selectivity in the channel?

A) The received signal Y is of the form Y = HX + w

Where H refers to flat fading which is a complex Gaussian RV. ‘w’ refers to the AWGN (additive white Gaussian noise) component which is additive in nature. Flat fading is small scale fading (one-tap), refers to the case where symbol time is large enough compared to delay spread caused by multi-path transmission. Rayleigh/Ricean are good statistical models for flat fading as they are inline with central limit theorem (sum of multiple independent RVs is Gaussian).

B) When the delay spread caused by multi-path fading becomes larger than the symbol duration, ISI results. There exist different gains for different frequency sections. This usually happens in broadband channels since the symbol time is relatively small. Frequency selectivity implies that over say 100 KHz, we assume the channel to be the same. Multi-path has multiple taps which leads to frequency-selectivity

C) Mobility causes the channel to change at each instant of time – Doppler effect. This generates additional frequency to modulate the “envelop” of the time domain signal. The time selectivity arises because we assume the channel to be the same over a period of 2.5 ms. This is referred to as coherence time.

IV. [4 pts] <u>Large-Scale Fading:</u>

1. Explain the difference between path loss and shadowing? What is the impact of shadowing on cell design?
2. Why does the 2-ray path loss model decay as $1/d^4$ and has no frequency dependence whereas the 1-ray LOS path loss model decay as $1/d^2$?

A) Path loss leads to a deterministic value of the received signal power given the transmitted signal power and the distance covered. Shadowing is in general random. Log normal shadowing is a good approximation to model the shadowing behavior. Shadowing considers path loss + blocking affect of transmission media. Considering shadowing the effective cell coverage no longer remains a disk, but becomes an irregular shape. Therefore outage probability at the edge of the cell becomes an important performance measure.

B) A 2-ray path loss model has a LOS and a reflected NLOS component which can constructively or destructively interfere with LOS component (hence the decay is 1/d^4). The 1-ray LOS path loss model delay is 1/d^2 since the electric field varies as 1/d from Maxwell's equations. Since lambda cancels out in the equation for received power, there is no frequency dependency in the 2-ray model.

V. [10 pts] <u>Probability:</u> A wireless channel has a BER (bit error rate) of 0.2, i.e. 20%. The transmitter wishes to transmit 15 bytes (= 120 bits) of data to the receiver. What is the expected number of bits that need to be transmitted on the channel for a successful transfer if :

a) The transmitter sends one ***bit*** at a time and retransmits each bit until it is successfully transferred.

b) The transmitter transmits one ***byte*** at a time and retransmits the whole byte if ***any*** one of the bits in the transmitted byte is in error.

Ignore the acknowledgement overheads.

A) Expected number of bits to transfer 1 bit successfully = 0.8*1 + 0.2*0.8*2 + … =

0.8*[1/(0.8*0.8)] = 1.25

Therefore expected number of bits to transfer 120 bits successfully = 120 *1.25 = 150 bits

B) Probability that one byte is transmitted successfully = 0.8^8 = 0.1678

Expected number of bytes to transfer 1 byte successfully = 1/0.1678 = 5.96 bytes = 47.68 bits

Therefore expected number of bits to transfer 15 bytes successfully = 15*47.68 = 715.26 bits

(5.96 rounded to 6 => 15*6*8 = 720 bits is also OK!)

❑ VI. **[10 pts] Linear Algebra:**

Consider the MIMO channel matrix H: $H = \begin{bmatrix} 7 & 3 \\ 3 & 1 \end{bmatrix}.$

Find its SVD (this decomposes the channel into parallel channels).

Matrix = [7 3 ; 3 2]

Since H is symmetric, $H H^T = H^T H$ = [58 27; 27 13]

Eigenvalues of HH^T = 0.3539 and 70.6457

Therefore sigma1 = 0.5949, sigma2 = 8.4051

$H = U \, Sigma \, V^T$

where

U = V = [-0.9056 -0.4242; -0.4242 0.9056]

Sigma = [8.4051 0; 0 0.5949]

SVD and eigen decomposition yield the same result. Therefore, V = U

VII. [10 pts] [Shadowing, Outage, Modulation Choice:] Consider a WiMAX base station (BS) communicating to a subscriber, with the channel parameters: path loss exponent (α) = 5, Po = −20dB, d0 = 1m, shadowing parameter (σ_s) = 5dB. We assume a transmit power of P_t = 0.1 Watt (20 dBm), a bandwidth of B = 10 MHz. A received SNR of 3 dB is required for coded BPSK demodulation. Consider ambient noise with a typical power spectral density of No = −173dBm/Hz, with an additional receiver noise figure of Nf = 4 dB (noise from all other sources).

- At a distance of 300 meters from the base station, what is the likelihood that the BS can reliably send BPSK? Use the simple empirical shadowing model:

$$P_r = P_t P_o \chi \left(\frac{d_o}{d}\right)^{\alpha}$$

Pr (dB) = 10 log Pt + 10 log P0 – 10 *alpha log d + 10 log X

= 20 dBm – 20 dB – 123.856 dB + X (dB)

= –123.856 dB + X (dB)

Noise power = N0 + Nf + 10 log B

= -173 dBm + 4 dB + 70 dB = -99 dB

SINR = -123.856 + X (dB) + 99 = - 24.856 dB + X (dB)

Without shadowing (X = 0) BPSK does not work (fails all the time!!)

With shadowing (sigma = 5dB) P [SINR > 3 dB] = P [X – 24.856/sigma > 3/sigma] = P[X/5 > 5.57] = Q(5.57) = $1.075 * 10^{-8}$

It is unlikely that BS can send reliably using BPSK at 300m due to large path loss (alpha = 5)