Formula Sheet - ES96T Advanced Wireless Networks

$$G_{dB} = 10 \cdot \log_{10}(G_W)$$

$$G_W = 10^{(G_{dB}/10)}$$

$$G_{dBm} = 10 \cdot \log_{10}(G_{mW})$$

$$G_{dBm} = 10 \cdot \log_{10}(G_W \cdot 1000)$$

Week 1

Bit rate example

Given 12 Mbps bit rate

QPSK 2 bits/symbol → 6 M symbols/s → 6 MHz Bandwidth

8-PSK 3 bits/symbol → 4 M symbols/s → 4 MHz Bandwidth

Name	Bits per symbol
BPSK	1 bits/symbol
QPSK	2 bits/symbol
8-PSK	3 bits/symbol
64-QAM	6 bits/symbol

Shannon Rate

$$R = B \cdot \log_2(1 + \mathrm{SNR}_{linear})$$

$$R = B \cdot \log_2(1 + \frac{P}{N_0 B})$$

where

$$N_0 = \text{Power spectral density}$$

> Maybe add Shannon for FDMA and TDMA

Week 2

Processing Gain

$$G_{linear}\ (\text{processing gain}) = \frac{R_c\ (\text{chip rate})}{R_s\ (\text{user data rate})} = \frac{1/T_c}{1/T} = \frac{T}{T_c}$$

$$SIR_f = SIR_b + G$$

$$SIR_f = \text{after de-spreading}, SIR_b = \text{before de-spreading}$$

$$SIR_{(b)} = \frac{P_S\ (\text{useful signal})}{P_I\ (\text{interference signal})}$$

Example N users in a cell

$$SIR = \frac{P}{(N-1)P} = \frac{1}{N-1}$$

Free space communication

$$P_r\ (\text{linear}) = P_T G_T G_r \left(\frac{\lambda}{4\pi r}\right)^2$$

$$P_T = \text{transmit power}, G_T = \text{transmit gain}, G_R = \text{receive gain},$$

$$\lambda\ (\text{wavelength})\ (\text{m}) = \frac{c}{f} = \frac{3 \cdot 10^8}{f}, r = \text{distance (m)}$$

Another version

$$P_r(\text{dBm}) = P_t(\text{dBm}) - 21.98 + 20\log_{10}(\lambda) - 20\log_{10}(d)$$

Noise power

$$P_N\ (\text{linear}) = kTB$$

$$k\ (\text{Boltzmann Constant}) = 1.38 \cdot 10^{-23}$$

$$T = \text{Temperature (Kelvin)}, B = \text{ Bandwidth (Hz)}$$

Week 3

Average SIR approximation

$$S/I = SIR\ (\text{linear}) = \frac{(\sqrt{3N})^n}{i_0}$$

$$N = \text{cluster size}, n = \text{path loss component}$$

$$i_0 = \text{number of adjacent cells (6 for hexagonal)}$$

Week 4

Power allocation strategies

Feature	Waterfilling	Mercury Filling	Channel Inversion
Objective	Maximize capacity by allocating power to better channels.	Maximize capacity while considering hardware constraints.	Ensure consistent signal strength at the receiver.
Channel Power Allocation	More power to better channels, less to weaker ones.	Modified based on constraints, penalizing certain channels.	More power to weaker channels, less to better ones.
Efficiency	Highly power-efficient, maximizing channel capacity.	Less efficient due to constraints but still optimized.	Power-inefficient, especially for poor channels.
Focus on Poor Channels	Low/no power for very poor channels.	Reduced power to penalized channels.	Allocates high power to poor channels.
Complexity	Simple to implement.	Moderately complex (accounts for imperfections).	Simple to implement.
Use Cases	OFDM, MIMO, and systems maximizing capacity.	Systems with hardware limitations (e.g., nonlinearities).	Systems needing uniform signal quality (e.g., fairness in service).
Impact on Capacity	Maximizes system capacity.	Slightly reduced capacity due to constraints.	Suboptimal capacity due to power wastage.

$$T_S = \frac{1}{\text{Bandwidth}}$$

$$\text{Data Rate (throughput)} = \frac{\text{number of bits}}{\text{symbol duration}}$$

$$\text{Data Rate (Throughput N Channels)} = \frac{\text{bits per symbol} \cdot \text{Number of channels}}{\text{total duration}}$$

$$\text{Overhead (N Channels)} = \frac{T_U}{\text{total duration}}$$

Total transmission time of the OFDM symbol

$$\text{total duration} = T_S \cdot (\text{Num channels}) + T_U$$

$$\text{Efficiency} = \frac{\text{throughput}}{\text{ideal TP}}$$

$$\text{Ideal TP} = \frac{\text{bits per symbol} \cdot \text{Number of channels}}{T_S \cdot (\text{Num channels})} = \frac{\text{bits per symbol}}{T_S}$$

Inter-Symbol interference exists when:
$T_D < T_S$
.

To avoid this we add
T_U
such that
$T_S + T_U \geq T_D$.

$$\text{Where } T_D = \text{Delay spread}, T_S = \text{Symbol duartion}, T_U = \text{Cyclic prefix duration}$$

Week 5

Water filling power allocation

$$\left(\frac{1}{x} - \frac{N_0}{|h_i|^2}\right)^+$$

$$\text{Where } N_0 = \text{Noise power}, \frac{1}{x} = \text{ Water level}, |h_i|^2 = \text{Subchannel gain. (All in W)}$$

Week 7

$$P_{\text{total}} = \frac{P_{RH}}{\text{efficiency}} \times \frac{T}{C} + P_{OH}$$

$$L\ (\text{load}) = \frac{T}{C}$$

Where

$$P_{\text{total}} = \text{Total power}, P_{RH} = \text{Radiohead power}, P_{OH} = \text{Overhead power}$$

$$T = \text{traffic demand}, C = \text{Capacity}$$

Week 8

Jain's Fairness

$$f(x_1, \ldots, x_n) = \frac{\left(\sum_{i=1}^{n} x_i\right)^2}{n \sum_{i=1}^{n} x_i^2}$$

Estimated Round Trip Time:

$$\text{Est}_{\text{RTT}} = (1-\alpha) \cdot \text{Est}_{\text{RTT}} + \alpha \cdot \text{Sample}_{\text{RTT}}$$

Deviation RTT:

$$\text{Dev}_{\text{RTT}} = (1-\beta) \cdot \text{Dev}_{\text{RTT}} + \beta \cdot |\text{Sample}_{\text{RTT}} - \text{Dev}_{\text{RTT}}|$$

Timeout Interval

$$\text{TI} = \text{Dev}_{\text{RTT}} + 4 \cdot \text{Dev}_{\text{RTT}}$$

$$\text{Loss Rate} = \frac{1}{\text{data sent with no interruptions}}$$

$$\text{Throughput} = \frac{\text{data per cycle}}{\text{time per cycle}}$$

Week 9

Vulnerable time

$$\text{Frame Rate} = \frac{\text{transmission rate}}{\text{frame size}} = \frac{1}{\text{frame duration}}$$

$$\text{Vulnerable time (Pure Aloha)} = 2 \cdot (\text{frame duration})$$

$$\text{Vulnerable time (Slotted Aloha)} = 1 \cdot (\text{frame duration})$$

Slotted Aloha Throughput

$$S\ (\text{Throughput}) = G \cdot e^{-G}$$

$$G\ (\text{traffic demand}) = \frac{\text{number of frames}}{\text{transmission time}}$$

$$T\ (\text{transmission time}) = \frac{\text{frame size}}{\text{rate}} = \frac{L}{R}$$

Probability of transmission

$$p = \text{Probability of a station to transmit}$$

Probability a (any) station transmits successfully

$$\text{Efficiency (Pure Aloha)} = N \cdot p \cdot (1-p)^{2(N-1)}$$

$$\text{Efficiency (Slotted Aloha)} = N \cdot p \cdot (1-p)^{N-1}$$

$$N = \text{Number of stations}$$

Probability that station X succeeds for the first time in slot M

$$P = \left(\left(1 - p(1-p)^{N-1}\right)^{M-1}\right) \cdot \left(p(1-p)^{N-1}\right)$$