EP21B015 Hariharan B

Assignment - 2

1. IoT systems typically have low data rates ($\leq$ 6.4 Kbps – assume BPSK modulation). Assuming the same transmitted power, justify how the low data rate system lead to better E_b / N_0 and hence to improved coverage compared to a cellular system like GSM which uses a signaling rate 270.833 Kbps.

E_b = energy per bit

$B \sim \frac{1}{T_s}$

$$\frac{P_s}{P_n} = \frac{E_b}{N_0 B T_b}$$

$$\frac{E_b}{N_0} = \left(\frac{P_s}{P_n}\right) B T_b$$

$$= \boxed{\left(\frac{P_s}{k_B T F}\right)} T_b$$

Constant

As Rate $\uparrow$, $T_b \downarrow$, $\frac{E_b}{N_0} \downarrow$

Thus, IoT has greater $\frac{E_b}{N_0}$ than GSM.

2. Consider GSM (200 KHz), CDMA2000 (1.25 MHz) and WCDMA (5 MHz) base-stations, wherein each transmits same power over the same distance.
   a. In which system will the receiver have the best SNR ? (C/N)
   b. What is the SNR improvement over the other two systems ?

Assume that in each case, thermal noise is the only impairment in the system.

$P_s(d) = P_{Tx} G_{Rx} G_{Tx} \left(\frac{\lambda}{4\pi d}\right)^2$ Friis's Law

a) As $\lambda \uparrow$, $P_s(d) \uparrow$ increases, hence $SNR \uparrow$ $[P_n$ is constant$]$

$\Rightarrow SNR_{GSM} > SNR_{CDMA2000} > WCDMA_{5MHz}$

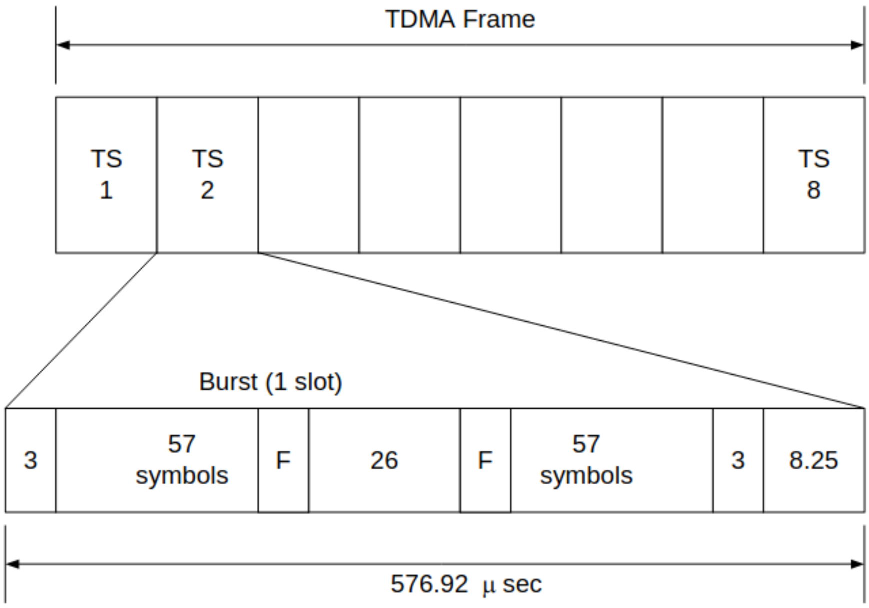
b) $\left.\begin{array}{l}SNR_{improvement} \\ \text{of GSM \& CDMA2000}\end{array}\right\} = \frac{SNR_{GSM}}{SNR_{CDMA2000}} = \frac{P_s(d)_{GSM}}{P_s(d)_{CDMA2000}} = \frac{\lambda_{GSM}}{\lambda_{CDMA2000}} = \frac{f_{CDMA2000}}{f_{GSM}}$

$SNR_{improvement}$ (in dB) $= \boxed{7.958 \text{ dB}}$

$SNR_{improvement}$ (in dB) of CDMA2000 vs WCDMA $= \frac{f_{WCDMA}}{f_{CDMA2000}} = \boxed{6.02 \text{ dB}}$

$\Rightarrow$ GSM is better than CDMA2000 by 7.9 dB & CDMA2000 is better than WCDMA by 6 dB

3. The GSM slot and frame structure are given in the attached figure. A user gets assigned one time slot per frame. User data is carried in 24 out of 26 frames in a multiframe. Note that each time slot has 2x57 data bits, 2x1 flag bits (F), 2x3 tail bits and 8.25 guard bits.
   a. What is the user data rate (assuming one slot is assigned to user)
   b. What would be the user throughput per slot if the flag and tail bits were converted to data symbols (in addition to the regular data fields)?



a) Data rate

$$= (\text{fraction of data frames in multiframe}) \times \frac{\#\text{ of data bits per frame}}{\cancel{\#\text{ of bits per frame}}} \times \frac{\cancel{\#\text{ of bits}}\text{ per frame}}{\text{Time per frame}} \times (\#\text{ of time slots per frame})$$

$$= \left(\frac{24}{26}\right) \times \frac{2\times 57\text{ bits}}{576.92\,\mu\text{sec}} \times \frac{1}{8}$$

$$= 22\,808\text{ bit/sec} = \boxed{22.8\text{ kbps}}$$

b) # of data bits / frame $= 2\times 57 + 2\times 1 + 2\times 3 = \boxed{122\text{ bits per frame}}$

$$(\text{fraction of data frames in multiframe}) \times \frac{\#\text{ of data bits per frame}}{\cancel{\#\text{ of bits per frame}}} \times \frac{\cancel{\#\text{ of bits}}\text{ per frame}}{\text{Time per frame}} \times (\#\text{ of time slots per frame})$$

$$\left(\frac{24}{26}\right) \times \frac{122\text{ bits}}{576.92\,\mu\text{sec}} \times \frac{1}{8} = \boxed{24.4\text{ kbps}}$$

4. An EDGE system uses a similar slot structure as GSM but 8PSK modulation. A minor change in the slot structure is made by converting the flag bits to data symbol (i.e., yielding a total of 116 data symbols per slot). Compute the user throughput per time slot for the EDGE system.

116 Symbols / slot

1 symbol = 8 bits

116 Symbols / slot = $\boxed{928 \text{ bits/slot}}$

# of bits / dataframe

$$= (\text{fraction of data frames in multiframe}) \times \frac{\text{\# of data bits per frame}}{\cancel{\text{\# of bits per frame}}} \times \frac{\cancel{\text{\# of bits per frame}}}{\text{Time per frame}} \times (\text{\# of time slots per frame}) \times \frac{T_s}{T_b}$$

$$= \frac{24}{26} \times \frac{116}{576.92} \times \frac{1}{8} \times 3 \Rightarrow \boxed{69.6 \text{ kbps}}$$

5. Consider a wireless communications link using QPSK modulation at a baud rate of 200 ksymbols per sec, using a channel with BW = 200 kHz. The Noise Figure of the receiver is 8 dB and signal power at the receiver is -102 dBm. Assume ambient temperature is 300K

   a. Compute the value of $\frac{P_S}{P_n}$
   b. Estimate the corresponding value of $\frac{E_b}{N_0}$
   c. If the modulation is changed to 8PSK, what will be the $\frac{E_b}{N_0}$ at the receiver (in dB)
   d. If the Rx antenna gain is - 2dB, what will be the $\frac{P_S}{P_n}$ (for QPSK modulation)

a) Noise floor $= k_B T F B$

$= -174\ \text{dB}(\text{Hz})^{-1} + 53\ \text{dB Hz} + 8\ \text{dB}$

$= \boxed{-113\ \text{dB}}$

$\frac{P_s}{P_n} = (-102 + 113)\ \text{dB} = \boxed{11\ \text{dB}}$

b) $\frac{E_b}{N_0} = \frac{P_s}{P_n} T_b B_{eq}$

$= \left(\frac{P_s}{P_n}\right) \frac{1}{2} T_s B_{eq} = \left(\frac{P_s}{P_n}\right)\left(\frac{1}{2}\right) \frac{1}{200\ \text{kHz}}\ 200\ \text{kHz} \Rightarrow 11\ \text{dB} - 2\ \text{dB} = \boxed{9\ \text{dB}}$

c) $\frac{E_b}{N_0} = \frac{P_s}{P_n} \underbrace{+ 10\log\left(\frac{1}{3}\right)}_{\text{For 8PSK}} = 11 - 4.7 = \boxed{6.3\ \text{dB}}$

d) $\frac{P_s}{P_n} = 11\ \text{dB} - 2\ \text{dB} = \boxed{9\ \text{dB}}$

6. Consider the link budget calculations done in class. Given the following detais: carrier frequency $f_c = 950\,MHz$. If the transmit power (EIRP) is 50 dBm, the propagation exponent is 3.5 and the receiver sensitivity is -102 dBm. The receiver has $NF = 9\,\text{dB}$. Calculate the following:
   a. The range of coverage assuming the breakpoint model with $d_{break} = 100$ m.
   b. What is the range if the propagation exponent $n = 4$
   c. If the receiver bandwidth is 30 KHz, what is the value of $SNR_{\min}$ that will experienced by the receiver

Assume Fading Margin = 0

50 dBm —— EIRP

Path loss

-102 dBm —— $P_{r,min}$ = Rx. sensitivity

Path loss for $d < d_{br}$

$$= \left(\frac{\lambda}{4\pi d_{br}}\right)^2 = \boxed{-72\,dB}$$

$$\lambda = 30/95 = \boxed{\frac{6}{19}\,m}$$

=> 80 dB path loss for $d > d_{br}$

a) $$80\,dB = 10 \times \log_{10}\left(\frac{d}{d_{br}}\right)^{3.5}$$

$$10^{2.28} = \frac{d}{d_{br}}$$

$$d = 19.05\,km = \boxed{19\,km}$$

b) $$80\,dB = 10 \times \log_{10}\left(\frac{d}{d_{br}}\right)^{4}$$

$$10^2 = \frac{d}{d_{br}}$$

$$\boxed{d = 10\,km}$$

c) Assume $T = 300K$

$$k_B T B = -174\,dBm/Hz + 44\,dB\,Hz = \boxed{-130\,dBm}$$

$$k_B T B F = \boxed{-121\,dB}$$

=> SNR_{min} = Rx. Sens. − Noise floor

$$= \boxed{19\,dB}$$

7. Consider a mobile radio system at 900 MHz carrier frequency, and with 25-kHz bandwidth, that is affected only by thermal noise (ambient temperature = 300K). Antenna gains at the Tx and Rx sides are 8 dB and −2dB respectively. Losses in cables, combiners, etc. at the Tx are 2 dB. The noise figure of the Rx is 7 dB and the bandwidth of the signal is 25 kHz. The required operating SNR is 18 dB and the desired range of coverage is 2 km. The breakpoint is at 10m distance; beyond that point, the path loss exponent is 3.8, and the fading margin is 10 dB. What is the minimum Tx power?

Noise floor $= k_B BTF$

$= -130\,dBm + 7\,dB = \boxed{-123\,dB}$

In breakpoint model:

Path loss $(d < d_{bp}) = \left(\frac{\lambda}{4\pi d}\right)^2 = \boxed{52\,dB}$

Path loss $(d > d_{bp}) = \left(\frac{d}{d_{bp}}\right)^{3.8} = \boxed{87\,dB}$

Total path loss $= \boxed{139\,dB}$

EIRP + 4 − 139 = −95 [in dB]

Tx + Rx Gain + Loss = $\boxed{6\,dB}$

$\boxed{EIRP = 60\,dB}$