Mid-Semester Test

Instructor-in-charge: B. Sainath, 2210-A, Electrical and Electronics Eng. Dept., BITS Pilani.

Course No./Title : EEE F430/Green communications and Networks

DATE: Mar. 16^{th}, 2023. Test duration: 90 Mins. Max. Points: 30.

(*Note*: You may use standard results or formulae by stating them explicitly. Highlight your final answers in rectangular boxes. Simplify your response to the extent possible. Use notation consistently.)

Part-I: Answer the following. (10 points)

Note: Each question carries 2 points. Write down the final simplified answer.

1. What are the key components of an autonomous wireless EH communication system? Suggest a method on improving energy efficiency of short-range communication technology.

2. Consider the transmission of information over a frequency-flat Raleigh fading channel. Assume a point-to-point wireless communication link. Compute the average SNR required to achieve an *average* bit error rate of 2×10^{-3} for $16-$QAM modulation. Assume that the total power consumption is 36 dBmW. What is the approximate energy efficiency? $\big($*Note:* Use the approximate formula and note that $\mathbf{E}\left[\exp(-s\gamma)\right] = \frac{1}{1+s\bar{\gamma}}$.$\big)$

3. Consider a dual-hop cooperative energy harvesting system (EH) with one relay (R) for RF EH and information transmission. The EH system comprises of half-duplex, single antenna nodes S, EH relay R. The model parameters are: Source node S transmit power 20 dBmW, $\gamma_{sr} \sim \exp(1)$, path loss factor and η both are 0.7. Further, the harvesting duration is 0.063 ms. Assuming time-switching relaying protocol, compute the average harvested energy in a frequency-flat Rayleigh fading channel. What is the relay transmit power (in milliwatts) if the transmission duration is 0.0185 ms?

4. Refer to Q. 3. above. Repeat the problem for the power splitting protocol. Compute the average harvested energy and transmit power (milliwatts). Assume power splitting ratio $\rho = 0.54$.

5. Consider a variable-rate M$-$QAM modulation scheme with two constellations, $M = 4$ and $M = 16$. Suppose $4-$QAM is used with probability 30% and $16-$QAM is used with probability 60%. The bandwidth efficiencies are 2 and 4, respectively. Assume that the bit rate is equal to channel capacity. Compute the average SNR (in dB). If the energy efficiency is 90 bps/Hz/watt, determine the total power consumption (milliwatts).

Part-II: Valid or Invalid (5 points)

Note: Write down Valid/Invalid. Justify in one or two sentences.

1) The main reason behind the success of short-range and long-range wireless systems has been the development of widely accepted standards.
2) Consider a wireless power transfer (WPT) circuit. For it, the circuit efficiency function is defined as the ratio of power delivered in the load to the power consumed at the source.
3) Consider Shannon's perspective for the WPT circuit based on inductive coupling. The maximum spectral efficiency across the channel when there is no constraint on the power delivered is attained by the famous waterfilling solution.

4) Consider the time-switching mode of operation in SWIPT with harvesting time $\alpha T = 0.5$ second, and the average fading channel power gain of the frequency-flat Rayleigh fading channel between the source to the energy harvesting relay is 1. Further, assuming the conversion efficiency and path loss factor are fixed and approximately equal to unity, the mean square value of the harvested energy is approximately equal to P_s^2, where P_s is the RF source transmit power.
5) Let λ denote the Lagrange multiplier in the waterfilling power allocation solution for the N_c subcarriers in the OFDM system. The height of the water surface is equal to $\frac{1}{\lambda^2}$.

Part III: Answer the following questions. (15 points) [*Note:* Provide key intermediate steps.]

Q. 1. (A) [*Waterfilling optimal power solution*] **[4.5 points]**

Consider a wireless system with 1 transmit antenna and L receive antennas. Statistically independent noise $\mathcal{CN}\,(0,\,1)$ corrupts the signal at each receive antenna. Due to $L > 1$ receive antennas, the overall channel power gain is given by $||\mathbf{h}||^2 = \sum_{n=1}^{L} |h_n|^2 \triangleq \gamma_L$.

For fast fading, with single transmit and receive antenna, the fading-averaged spectral efficiency (FASE) is given by

$$\text{FASE} = \mathbf{E}\left[\log_2\left(1 + |h|^2 P_t(\gamma)\right)\right],$$

where P_t denotes the transmit antenna power.

For the $L-$ receive antenna model, consider the average power constraint: $\mathbf{E}\left[P_t(\gamma_L)\right] = P_{av}$. Assuming full CSI, ignoring path loss, answer the following:

i). Formulate the constrained optimization problem on FASE. Formally, state the problem. [1 point]

ii). Using the Lagrange multipliers approach, determine the optimal P_t (i.e., P_t^*) and optimal FASE. Determine the fading-averaged energy efficiency (FAEE) associated with the optimal transmit power. P_{crt} denotes power consumption in circuitry and P_{csi} is the power consumed for CSI acquisition.

[2 + 1.5 points]

(B) [*SE and EE outage probabilities*] **[3.5 points]**

i) Consider the frequency-flat fading channel. The instantaneous SE is given by $\log_2\left(1 + \gamma_L P_t(\gamma_L)\right)$. Let the SE threshold be $\mathbb{S}_{E,th}$. The approximate probability density function of γ_L is given by $p_{\gamma_L}(y) \approx \frac{y^{L-1}}{(L-1)!}$, $y > 0$. Obtain an analytical expression for the SE outage probability ($p_{\text{out},SE}$). [2 points]

ii). Consider the frequency-flat fading channel. The instantaneous EE is given by $\frac{\log_2(1+\gamma_L P_t(\gamma_L))}{P_{Tot}}$, where P_{Tot} denotes the total power consumption. Let the EE threshold be $\mathbb{E}_{E,th}$. The approximate probability density function of γ_L is given by $p_{\gamma_L}(y) \approx \frac{y^{L-1}}{(L-1)!}$, $y > 0$. Obtain an analytical expression for the EE outage probability ($p_{\text{out},EE}$). Compare and comment on energy efficiency outage probability for $L = 1$ and $L > 1$.

[1.5 points]

Q. 2. [*Simultaneous Wireless Information and Power Transfer (SWIPT)*]

Answer the following: **[7 points]**

i). What are the four types of SWIPT receiver architectures? Specify their names. [2 points]

ii). Neatly sketch the simplified block diagrams of the two practical SWIPT receiver architectures. In each illustration, mention the building blocks and other key parameters. [2 + 2 points]

iii). Mention an application of SWIPT in green communication systems with an illustration. [1 point]

□ END OF QUESTION PAPER □