EECE5155: Wireless Sensor Networks and the Internet of Things
Numerical Homework Assignment

Given: November 23, 2020
Due: December 13, 2020 (11:59 PM)

Submission Instructions:

Submit your assignment directly on Canvas

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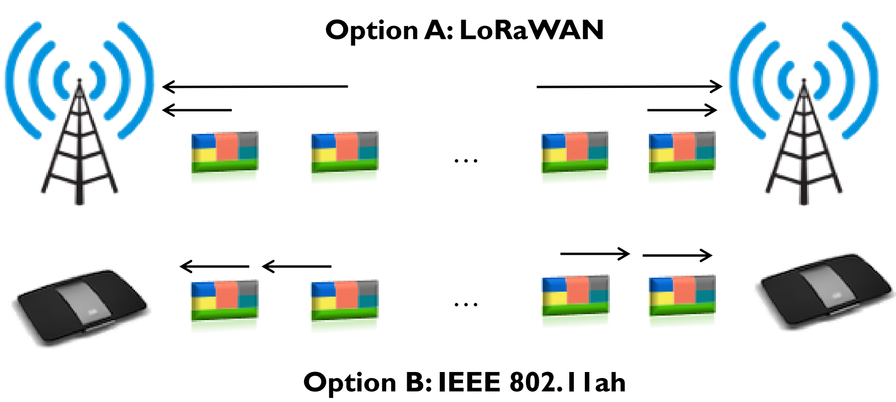
In this assignment, you are going to be working on the design of a wireless sensor network for air pollution monitoring in cities. In this application, a large number of (ideally cheap) outdoor sensors deployed within a city (e.g., on building facades and rooftops, light posts, etc.) are periodically measuring the presence of pollutants in the air. The measured information is transmitted over the Internet to a cloud server, where data is both analyzed and stored.



PART 1

In the first part of the assignment, you are going to quantitatively analyze the impact of different communication system parameters on the aforementioned application. For this, you can utilize MATLAB or any other numerical analysis toolbox (e.g., NumPy). Remember that MATLAB is available for free to all Northeastern students (check the Announcement on Canvas from September 11, 2020).

Question 1: Compute and plot the path loss as a function of the transmission distance. Consider multi-path propagation with a reference distance of d_0=1 m, and a propagation exponent of γ=3.2. Nodes operate at the 900 MHz Industrial, Scientific and Medical (ISM) band, with omnidirectional antennas (G_{tx}=G_{rx}=0 dBi). Please remember to label your axis, indicating both the magnitude and its unit (e.g., 'Distance [m]'). (10 points)

To enable the communication between the nodes and ultimately the cloud, we consider two communication alternatives:

- Option A: Low-Power Wide Area Network based on LoRaWAN:
    - Direct communication from each node to its closest base station (BS).
    - Bandwidth: 500 kHz.
    - Spreading factor: SF8
    - Data-rate: 12.5 kilo-bits-per-second (kbps)
    - The BS equivalent noise power of -100 dBm.
        - A signal to noise ratio of at least 20 dB is needed to ensure that the Bit Error Rate (BER) is of 10^{-5} at most.

Question 2: What is the minimum received power at the BS needed to satisfy the BER requirement? (5 points)

Question 3: Compute and plot the required transmission power as a function of the distance between a node and the BS. (5 points)

Question 4: If your maximum transmission power is 20 dBm, what should be the maximum separation between two BSs? (5 points)

Question 5: For the same transmission power, how much energy will a node consume when transmitting a 20 byte-long packet? At this point, ignore the energy consumption of acknowledgment frames or any other non-DATA message exchange. (5 points)

- Option B: Ad Hoc Network based on IEEE 802.11ah:
    - Consider that instead of installing LoRaWAN BSs, you are deploying Access Points (APs) every 150 m.
    - Bandwidth: 1 MHz.
    - Data-rate: 300 kbps
    - The equivalent noise power both at each node and at the AP is -80 dBm.
        - A signal to noise ratio of at least 20 dB is needed to ensure that the BER is of 10^{-5} at most.

Question 6: What is the minimum received power at any node needed to satisfy the BER requirement? (5 points)

Question 7: Compute and plot the required transmission power as a function of the distance between two nodes. (5 points)

Question 8: If the maximum transmission power of each node is 10 dBm, how many transmissions will be required for a message from a node at 75 m to reach the AP? Remember that the number of transmission can only be an integer value. (5 points)

Question 9: How much energy will be consumed to transmit 20 bytes from the node at 75 m to the AP? You can ignore the receiving and the computing power (they are comparably much lower than the transmission power). Similarly, at this point, ignore the energy consumption of acknowledgment frames or any other non-DATA message exchange. (5 points)

Question 10: From the energy consumption perspective, which option would you prefer: A (LoRaWAN) or B (IEEE 802.11ah)? Briefly justify your answer. (10 points)

Bonus: Question 11: Intuitively (no need to redo the numbers, unless you really want to), what would happen if you were asked to operate the two networks at 2.4 GHz? Briefly explain your answer. (Bonus 5 points)

PART 2

In the second part of the assignment, you are going to qualitatively discuss some of the aspects relating to the link layer and above. Provide brief explanations for each question.

Question 12: From the link layer perspective and, particularly, Medium Access Control (MAC), which network is easier to operate, a LoRaWAN network or an Ad Hoc IEEE 802.11ah network? In which network there will be a larger number of control and data messages being exchanged? (10 points)

Question 13: Explain the main differences between the network layer needed to support the LoRaWAN scenario and the one needed to support the IEEE 802.11ah network. In particular,

- **How can a node know to whom relay its information?**
- **As a result, in which network do you expect more messages flowing?**

(10 points)

Question 14: Focusing on the IEEE 802.11ah network, what type of routing protocol (i.e., proactive or reactive) would you utilize if:

- **Sensors are periodically sending their measurements, independently of their value**
- **Sensors only send a message if the air pollution is above a certain safety limit**

(10 points)

Question 15: Based on these discussions, which option would you prefer: A (LoRaWAN) or B (IEEE 802.11ah)?
(10 points)

Prepare a brief report INTEGRATING your scripts, figures and answers for each of the aforementioned questions, in one file.