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EECE 5155
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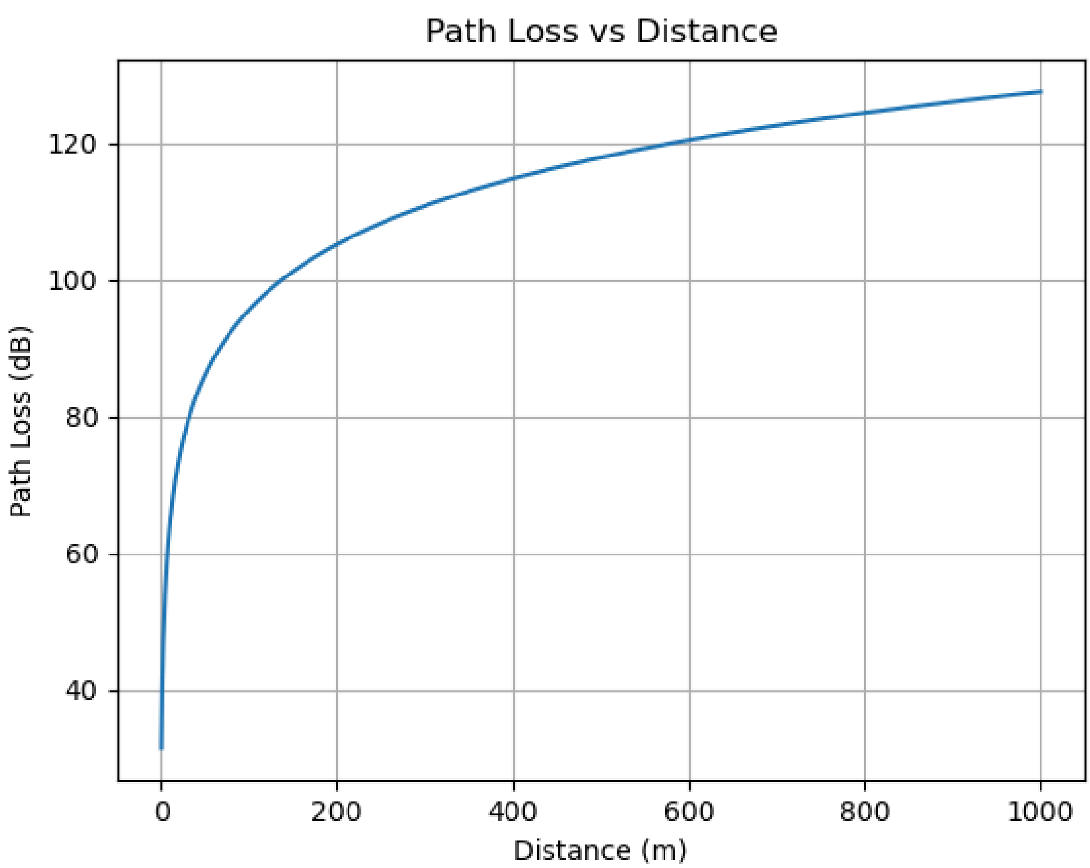
Homework Assignment

Question 1

Compute and plot the path loss as a function of the transmission distance. Consider multi-path propagation with a reference distance of d0=1 m, and a propagation exponent of lambda =3.2. Nodes operate at the 900 MHz Industrial, Scientific and Medical (ISM) band, with omnidirectional antennas (Gtx=Grx=0 dBi). Please remember to label your axis, indicating both the magnitude and its unit (e.g., 'Distance [m]').
NOTE: All references of path_loss is referring to this function

```python
def path_loss(distance, frequency):
    """
    Calculate the path loss in dB using the free space path loss model.

    Parameters:
    distance (float): Distance in meters
    frequency (float): Frequency in Hz

    Returns:
    float: Path losses in dB
    """
    c = 3e8  # Speed of light in m/s
    wavelength = c / frequency  # Wavelength in meters

    d0 = 1  # Reference distance in meters
    gamma = 3.2 # Path loss exponent for urban environments

    Gtx = Grx = 0 # Transmitter and receiver gains in dBi

    step = distance / 0.1 # Step size for distance
    d = np.linspace(1, distance, int(step)) # Distance array from 1 to the specified distance

    pl_d0 = 20 * np.log10(4 * np.pi * d0 / wavelength) # Path loss at reference distance
    print(f"Path loss at reference distance (d0): {pl_d0} dB")
    path_loss = pl_d0 + 10 * gamma * np.log10(d / d0) + Gtx + Grx  # Path loss formula

    return d, path_loss
```

```python
if (q_num == 1):
    distance = 1000 # Distance in meters
    frequency = 900e6 # Frequency in Hz

    # Get path loss
    distances, losses = path_loss(distance, frequency)

    # Plot the path loss
    plt.plot(distances, losses)
    plt.title('Path Loss vs Distance Q1')
    plt.xlabel('Distance (m)')
    plt.ylabel('Path Loss (dB)')
    plt.grid()
    plt.show()
```



Question 2

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

P_N = -100 dB

SNR = 20dB

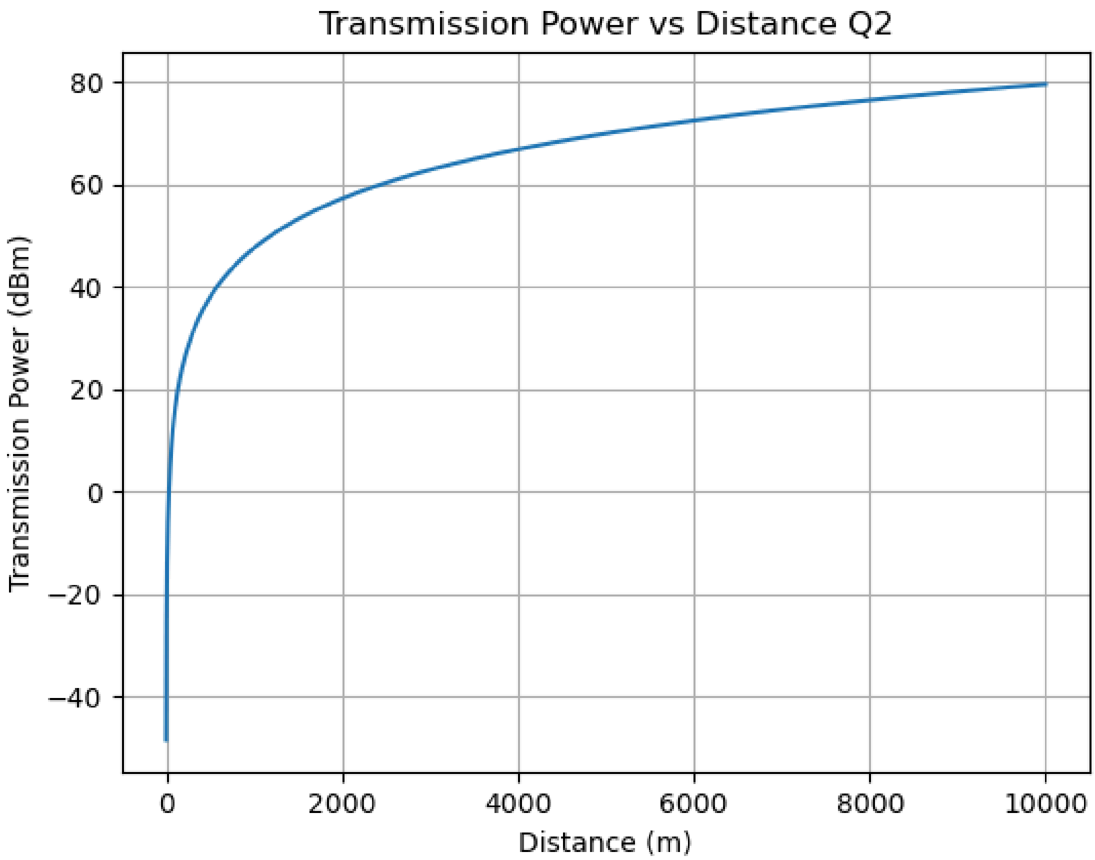
$P_{Rx} = P_N + SNR$

P_{Rx} = -80dB

Question 3

Compute and plot the required transmission power as a function of the distance between a node and the BS

```
elif (q_num == 3):
    distance = 10000 # 10 kilometers
    frequency = 900e6 # Frequency in Hz

    # Get path loss
    distances, losses = path_loss(distance, frequency)
    print(f"Path Loss: {losses[0]}")

    p_rx = -80 # Receiver power in dBm
    trans_power = p_rx + losses

    plt.plot(distances, trans_power)
    plt.title('Transmission Power vs Distance Q3')
    plt.xlabel('Distance (m)')
    plt.ylabel('Transmission Power (dBm)')
    plt.grid()
    plt.show()
```



Question 4

If your maximum transmission power is 20 dBm, what should be the maximum separation between two BSs?

```python
# Constants
distance = 10000 # 10 kilometers
frequency = 900e6 # Frequency in Hz
d0 = 1
n = 3.2
c = 3e8
wavelength = c / frequency

# Get path loss
distances, losses = path_loss(distance, frequency)

p_tx = 20 # Transmitter power in dBm
p_rx = -80 # Receiver power in dBm
# p_tx = p_rx + losses
# loss @ d = p_tx - p_rx = 20 - (-80) = 100
p_max = p_tx - p_rx # Maximum path loss

# solve for d using loss = 100 dB
idx = min(range(len(losses)), key=lambda i: abs(losses[i] - p_max))
res = distances[idx]
print(f"Distance for 100 dB loss: {res} m")
```

```
aliu@Alston-PC:~/EECE5155_HW/part1$ python3 path_loss.py --question 4
Running Question: 4
Path loss at reference distance (d0): 31.52662237483517 dB
Distance for 100 dB loss: 137.98766987669876 m
```

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.

20 bytes = 160-bits

$P_{Tx} = 20 \text{ dBm} = 10^{(P_{dBm}/10)} * 10^{-3} = 0.1 \text{ W}$

$R_{data} = 12.5 \text{ kbps} = 125000 \text{ bps}$

$t = data / rate = 160 / 12500 = 0.0128s$

$E = P\,x\,t = 0.1\,W * 0.0128s = 1.28\,mJ$

Question 6

What is the minimum received power at any node needed to satisfy the BER requirement?

P_N = -80 dB

SNR = 20dB

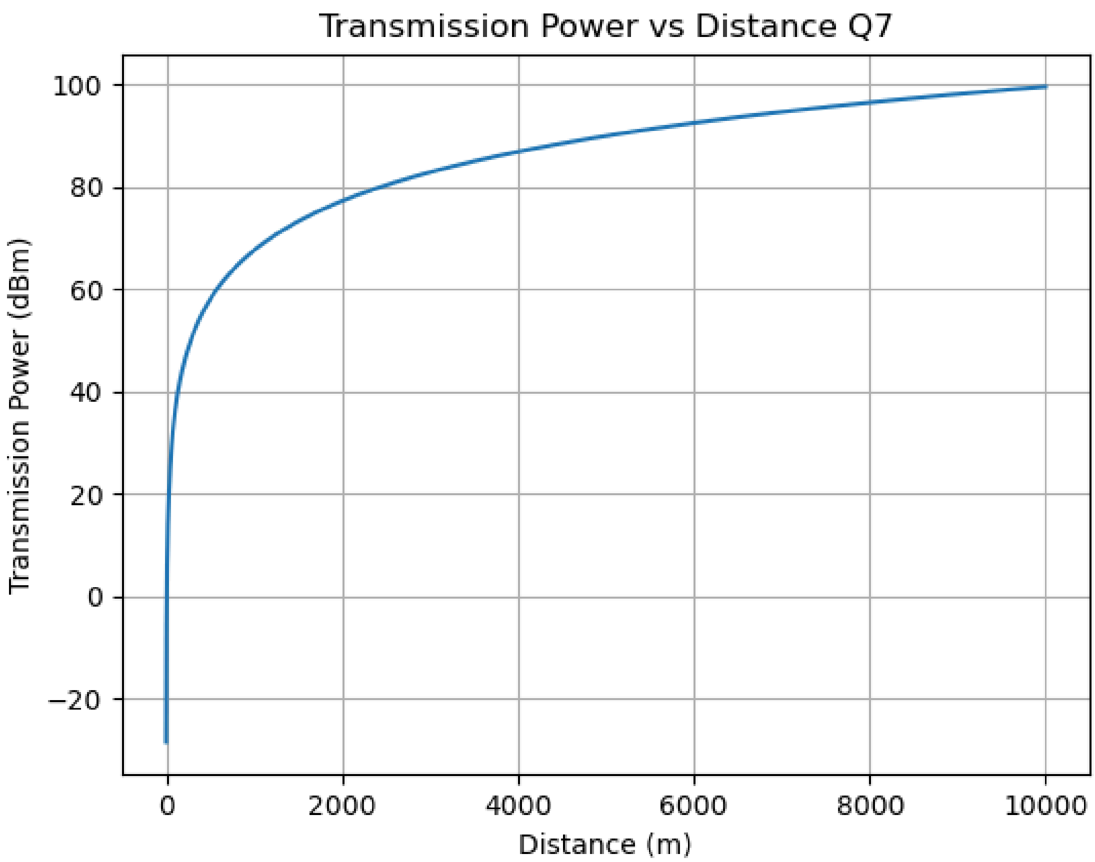
$P_{Rx} = P_N + SNR$

P_{Rx} = -60dB

Question 7

Compute and plot the required transmission power as a function of the distance between two nodes.

```
elif(q_num == 7):
    # Constants
    distance = 10000
    frequency = 900e6

    # Get path loss
    distances, losses = path_loss(distance, frequency)
    print(f"Path Loss: {losses[0]}")

    p_rx = -60 # Receiver power in dBm
    trans_power = p_rx + losses

    plt.plot(distances, trans_power)
    plt.title('Transmission Power vs Distance Q7')
    plt.xlabel('Distance (m)')
    plt.ylabel('Transmission Power (dBm)')
    plt.grid()
    plt.show()
```



Question 8

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

```python
elif(q_num == 8):
    # Constants
    distance = 10000
    frequency = 900e6 # Frequency in Hz
    d0 = 1
    n = 3.2
    c = 3e8
    wavelength = c / frequency
    p_tx = 10 # Transmitter power in dBm
    p_rx = -60 # Receiver power in dBm
    p_max = p_tx - p_rx # Maximum path loss

    # Get path loss
    distances, losses = path_loss(distance, frequency)

    # solve for d using loss = 100 dB
    idx = min(range(len(losses)), key=lambda i: abs(losses[i] - p_max))
    res = distances[idx]

    print(f"Distance for 1 hop: {res} m")

    ap_dist = 75
    hops = int(np.ceil(ap_dist / res))
    print(f"Number of hops: {hops}")
```

```
Running Question: 8
Path loss at reference distance (d0): 31.52662237483517 dB
Distance for 1 hop: 15.898658986589867 m
Number of hops: 5
```

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.

```
elif(q_num == 9):
    distance = 10000

    p_tx = 10
    p_rx = -60

    data_size = 160
    data_rate = 300000

    # Calculate the time taken to transmit the data
    time = float(data_size) / data_rate
    p_tx = 10 ** (p_tx / 10) * 1e-3 # Convert dBm to Watts

    E = p_tx * time # Energy consumed per hop
    total_E = E * 5 # Total energy consumed for 5 hops
    print(f"Total energy consumed: {total_E} J")
```

Question 10

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

In terms of power consumption, option B uses far less with 0.0267mJ while option A uses 1.28mJ for the same amount of bytes. Even though option B requires 5 hops, it has a significantly higher data rate which would amount to shorter transmission time. It uses less transmission power and is more efficient than the LoRaWAN.

LoRaWAN is ideal for ultra-low power devices with very infrequent communication since it allows long sleep periods and a minimal duty cycle. IEEE 802.11ah is better suited for applications needing more frequent communication or larger data throughput. While LoRaWAN excels in total energy efficiency over time, IEEE 802.11ah is more energy-efficient per bit transmitted, especially in active networks.

Question 11

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?

From a link layer and MAC perspective, LoRaWAN is significantly easier to operate than an Ad Hoc IEEE 802.11ah network. LoRaWAN uses a simple ALOHA MAC protocol. Nodes transmit without sensing the medium and do not coordinate. This leads to minimal control overhead, making it well-suited for low-power, low-traffic applications.

An IEEE 802.11ah Ad Hoc network relies on a more complex MAC protocol (based on Wi-Fi), which uses CSMA/CA, and supports RTS/CTS handshakes, association procedures, beaconing, and collision avoidance. In Ad Hoc mode, nodes must also discover neighbors and potentially exchange routing information, especially in multi-hop scenarios.

As a result, IEEE 802.11ah will generate more control and data messages, due to its more interactive and coordinated channel access. LoRaWAN, by design, minimizes such exchanges to reduce energy consumption and simplify operations.

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?

LoRaWAN uses a centralized, star topology where nodes send data directly to gateways, which forward it to a central server. Each node has a unique DevEUI and does not relay messages, so no routing is needed. This simplicity reduces message overhead, making LoRaWAN ideal for low-power, infrequent communication. However, nodes cannot choose gateways or make routing decisions.

In contrast, IEEE 802.11ah supports flexible topologies (star, mesh, hybrid) and can operate in ad hoc mode, where nodes must discover routes and relay data for others using MAC addressing and routing protocols. This enables higher throughput and adaptability but also generates more control and data messages due to multi-hop communication and routing maintenance.

Thus, 802.11ah networks have higher message flow, while LoRaWAN is simpler and more energy-efficient for low-data IoT use cases.

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
In an IEEE 802.11ah network:

- For periodic measurements, a proactive routing protocol like OLSR is most appropriate. These protocols maintain routing tables at all times, ensuring immediate route availability and low latency when data is sent. However, they generate constant control message overhead, even when no data is being transmitted.

- For threshold-triggered communication (e.g., only sending data when pollution exceeds a limit), a reactive routing protocol like AODV is preferable. It establishes routes only when needed, reducing control overhead and saving bandwidth. The trade-off is a delay in route discovery and potential vulnerability to topology changes during route setup.

Question 15

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

LoRaWAN (Option A) is preferred for most low-power IoT applications due to its exceptional energy efficiency, long-range connectivity, and simple, scalable star topology. It operates cost-effectively in unlicensed bands and uses Adaptive Data Rate (ADR) to optimize reliability and network capacity.

While IEEE 802.11ah (Option B) supports higher data rates and flexible topologies, it requires more complex routing and results in higher control overhead and energy consumption, especially in multi-hop scenarios.

For energy-critical, low-data applications, LoRaWAN is the better choice.