Wireless Networking

Course code: CS4222/5422, Tutorial session: #8

Brief Instructions regarding the tutorial session

1. The attendance to tutorial sessions would contribute towards the determination of final grade
2. Please review the questions before coming to the tutorial session
3. Make an effort to solve the questions before attending tutorial. The teaching assistants will help in case of issues
4. The designated time for the tutorial session is one hour. Please contact the teaching assistants or the instructor if you need any further clarification regarding the tutorials outside the allocated period. Please send them an email.

Question 1: A node running BMAC spends its time in the following 4 states: (1) sleeping (consumes 1mW), (2) idle listening (consumes 10mW), (3) receiving (consumes 20mW), and (4) transmission (consumes 20mW). Note that in the idle listening state, a node detects channel activity but does not receive data. In the receiving state, there is actual packet reception. By default, the node wakes up every 250ms to sample the channel for a duration of 5ms. Every 5s, the node transmits or receives a packet with equal probability. Packet transmission or reception duration is always 5ms. On average, what is the percentage of the energy spent on:

a) sleeping
b) idle listening
c) receiving
d) transmission

If the battery used provides 1 KJ of energy, what is the lifetime of the node?

Answer 1:

In transmission cycle, 250ms + 5ms

2.5% (1/20 *0.5) Active send = 0.255 x 20 mW (T)

2.5% (1/20 *0.5) Active recv = 0.125 x 1mW (S) + 0.125 x 10mW (I) + 0.005 x 20mW (R)

95% Idle = 0.005 x 10mW (I) + 0.245 * 1mW (S)

sleeping (S) = 0.95 * 0.245 * 1 + 0.025 * 0.125 * 1 = 0.23275 + 0.003215 = 0.235875 mW

idle listening (I) = 0.95 * 0.005 * 10 + 0.025* 0.125 * 10 = 0.07875

recv (R) = 0.025 * 0.005 * 20 = 0.0025

transmit (T) = 0.025 * 0.255 * 20 = 0.1275

total = 0.4446 mW

a) sleeping = (0.236/0.4446) = 53.1%
b) idle listening ~ 17.7%
c) receiving ~ 0.56%
d) transmit ~ 28.7%
e) Average power = 0.4446 mW. 1KJ = 1kWs. Therefore lifetime = 1K/(0.4446 * 10^-3)

Question 2: Assume you have an IoT device equipped with ZigBee, LoRa, and Wi-Fi radios, powered by a coin cell battery with a capacity of 240 mAh. Given the radio configurations below, please calculate the energy per bit for each technology. Based on the results, discuss the advantages and disadvantages of each wireless communication method.

Communication Technology	Bitrate	Transmit Current (mA) @ 3 V
Wi-Fi (802.11b)	11 Megabits/ second	170 mA (at 17 dBm)
ZigBee	250 kilobits/ second	9.1 mA (5 dBm)
LoRa	27 Kilobits/second	87 mA (17 dBm)

Answer 2:

WiFi: (170 mA * 3)/ 11 = 510 mW/11,000,000 = 46.36 nJ/bit

ZigBee: (9.1 mA * 3V)/250,000 = 109.2 nJ/bit

LoRa: (87 mA * 3V)/27,000 = 9667 nJ/bit

WiFi: It has lowest energy per bit. However, it has short range. Good for applications transmitting lot of data over short distances

ZigBee: Good for sending reasonable amounts of data over similar or slightly more range than WiFi. Commonly used in battery-powered IoT devices. Can also be used for mesh networks

LoRa: Good for applications requiring transmission of small amounts of data over hundreds of meters of distances. None of other standards support such high range

Sensors in agriculture: Large range, small amounts of data -> LoRa seems most appropriate

Smoke alarms: Might require smoke alarms to talk to each other, communicate over a short range, are battery-operated, and need to last long, small amounts of data -> ZigBee seems appropriate

Security camera: Large amounts of data, typically short range -> WiFi may be appropriate

Question 3: You have been provided with an IoT device that utilizes an active radio and highly energy-efficient wake-up receivers. These receivers facilitate low-power idle mode and channel sensing. Ordinarily, the nodes remain in sleep mode for the majority of the time, briefly waking up (for 1 data packet duration) to use the wake-up receiver for looking/sensing for active transmission. If a transmission is detected, they transition into reception mode. The transmitter employs a mechanism akin to X-Mac and Contiki MAC, repeatedly sending data packets rather than transmitting an explicit preamble message.

Radio Mode	Transmit Current (mA) @ 3 V
Sleep	0.01
Active (Transmission)	10
Active (Reception)	10
Channel Sensing	0.1

The device employs a transceiver with PHY supporting a 250 kilobits/second bitrate. The size of a data packet (with all fields included) is 127 bytes. The device performs channel sensing every 100 milliseconds. Given the power consumption, please perform the following calculations:

Please note: We define one radio cycle as period between two channel sensing events, i.e., one radio cycle is 100 milliseconds long.

a) What is the transmission time for a data packet?
b) What is the maximum number of data packets the transmitter would need to send?
c) What is the average power consumption of one radio cycle when no transmission is occurring, and when there is a data transmission?

Answer 3:

(a) Data packet size is 127 bytes, So, there are 127 * 8 = 1016 bits in a data packet.

The PHY supports a bit rate of 250 kilobits/second, which is 250,000 bits/second.

Transmission time = (Data packet size in bits) / (Bitrate)
Transmission time = 1016 bits / 250,000 bits/second
= 0.004064 seconds or 4.064 milliseconds

(b) The transmitter employs a mechanism like X-Mac and Contiki MAC, it repeatedly sends data packets instead of transmitting an explicit preamble message.

Let's find out how many data packets can be sent within the 100-millisecond radio cycle, considering the channel sensing time.

Available time for transmission in one radio cycle = Total cycle time
Available time for transmission in one radio cycle = 100 ms

Now, we find maximum number of data packets that can be sent within this available time:

Max number of packets = Available time for transmission / Transmission time data packet

Max number of data packets = 100 ms / 4.064 ms ≈ 24

Please note: We can't send a fraction of a packet; we round down to the nearest number.
Maximum number of data packets the transmitter needs to send = 24

(c) When no data transmission occurs, we are only performing channel sensing task.

The device spends most of its time in the sleep mode.

Sleep period duration = Total radio cycle time - Channel sensing time
Sleep period duration = 100 ms - 4.064 ms = 95.936 ms

Channel sensing period duration = Transmission time for a data packet = 4.064 ms

Energy Consumption Measurements:

Energy consumption during sleep mode = Sleep current * Voltage * Sleep period duration
Energy consumption during sleep mode = 0.01 mA * 3 V * 95.936 ms = 2.87808 micro joules

Energy consumption = Sensing current * Voltage * Time
Energy consumption = 0.1 mA * 3 V * 4.064 ms = 1.2192 micro joules

Energy consumption during a radio cycle = 2.87808 + 1.2192 = 4.09728 micro joules

Power Consumption Measurements:

We can calculate using average current. We start by finding time spent in various modes.

One radio cycle: 100ms + channel sensing time

Note: You can also assume radio cycle to be 100ms with channel sensing time included. Both answers will be considered correct.

Channel sensing time: 4.064 milliseconds
Percentage of time (channel sensing) in one radio cycle: 4.064/(100+4.064) = 3.9%
Transmission: 0%
Reception: 0%
Sleep: 100-3.9% = 96.1 %

Average current: (0.039 * 0.1 + 0.961 * 0.01) mA = 0.01351 mA
Average power consumption: 0.01351 * 3 = 0.04053 mW

Now, let's consider the case when transmission occurs:

In the case of data transmission.

Transmitter would send 24 data packets (to wake up receiver)

Energy consumed (Transmissions): 24 * 4.096 * 3V * 10 micro joules

Energy consumed (Receptions): 1 RX + 1 Sleep = 95.036*3*0.01 + 4.064*3*10 microjoules

Power Consumption Measurements

One radio cycle: 100ms + channel sensing time

Transmitter (Active duration): (24*4.064) /(100+4.064) = 94.72 %
Sensing: 4.064/(100+4.064) = 3.9 %
Sleep: 1.38 %

Average Current Consumption: (0.9472*10+ 0.039*0.1 + 0.0138 * 0.01) mA = 9.48 mA
Average Power Consumption (Transmitter) = 9.48 *3 mW

On Receiver:

Channel Sensing and Reception are Same (In this case): 4.096 ms = 3.9%
Percentage of time (channel sensing) in one radio cycle: 4.064/(100+4.064) = 3.9%
Transmission: 0%
Reception: 3.9%
Sleep: 100-3.9% = 96.1 %

Average current: (0.039 * 0.1 + 0.961 * 0.01) mA = 0.01351 mA
Average power consumption: 0.01351 * 3 = 0.04053 mW