Wireless Networking (Solutions)

Course code: CS4222/5422, Tutorial session: #1

Question 1: Is it permissible to transmit radio signals on any frequency band? What are the frequency bands typically used for wireless communication in IoT devices called? Can you identify these frequency bands in region of Europe, Singapore, and the United States?

Answer 1: No, you are not allowed to transmit radio signals onto any frequency band. You are only allowed to transmit on designated bands that allow unlicensed transmissions.

Commonly, for IoT devices we use bands which are called ISM frequency bands. ISM stands for Industrial, Scientific, Medical radio bands.

They are at 868 MHz, 900 MHz, 2.4 GHz and 5.725 GHz. The specific allocation may differ from one region to another. We illustrate ISM bands (for IoT devices) for different parts of the world :

Region	Bands
Europe	865-868 MHz, 2.4 GHz, 5 GHz
Singapore	2.4 GHz, 866-869 MHz, 923-925 MHz, 5 GHz
United States	900 MHz, 2.4 GHz, 5 GHz

Question 2: You are in charge of designing an IoT device. Considering the relationship between antenna size, frequency, and range, what type of antenna would you employ? What typical data rate can you expect, and what operating frequency would you choose?

Internet of Things Application	Description
Fire alarm	A fire alarm that keeps track of smoke and heat signature in home. When it encounters a fire, it generates a sound, and communicates the event to the owner of the house and other devices.
Vibration sensor	A sensor designed to keep track of vibrations of machine on a shop floor. The collected vibration data from several machines to an edge device for storage and analysis.
Agriculture sensor	An IoT device deployed on a farm to measure humidity, temperature and soil nutrients. The collected sensor data needs to be transmitted to a computer at center of farm for storage and analysis.

Answer 2:

Internet of Things Application	Description
Fire alarm	**Antenna:** omnidirectional, likely monopole or a patch antenna to enable uniform radio propagation **Frequency:** ISM: 433 MHz, 868 MHz, 2.4 GHz **Data rate:** few hundred bits to few kilobit/second. Only need to communicate event that the fire or smoke sensor was triggered.
Vibration sensor	**Antenna:** directional antenna owing to complex environment to reach edge device. Omnidirectional (is okay, but not preferred) **Frequency:** ISM: 868/900 MHz enable significant range in a complex environment. Lower frequency propagates better and farther. 2,4 GHz may work if edge device is located very close to the sensor. **Data rate:** Tens to few hundred kilobit/second. 1 axis accelerometer (8-bit), X-Y-Z (Three axis), captured few hundred time a second
Agriculture sensor	**Antenna:** Directional antenna would be preferred, as may have to reach a central server located significant distance away from the sensor. **Frequency:** ISM: 868/900 MHz or much lower. Enables us to communicate over large distances for the same transmit power. **Data rate:** Few kilobits/second.

Question 3: There has been growing interest in connecting devices using a network of small satellites. For example, the SpaceX swarm is providing one such service. Most of these networks currently focus on providing downlink connectivity from the satellite to a ground device. Let's now consider the possibility of IoT devices communicating directly with an overhead satellite. The goal is to transmit small amounts of information from the IoT device to the satellite and vice versa. You can assume that the satellite is orbiting in a low earth orbit of 400 kilometres from the surface.

Answer 3: Let us recall the Friis propagation equation:

$$P_r = G_r G_t \left(\frac{c}{4\pi f_c d} \right)^{\alpha} P_t$$

$$1] \quad P_{rx} = P_{tx} G_{tx} G_{rx} \left(\frac{c}{4\pi D_r f_0} \right)^2$$

$$2] \quad P_{rx}(dB) = P_{tx} + G_{tx} + G_{rx} + 20 \log_{10} \left(\frac{\lambda}{4\pi D_r} \right)$$

For the sake of simplicity, let us consider the value of the parameter alpha to be 2.

a) What frequency would you like to use for communication? What are the factors based on which you would decide the appropriate frequency to employ for the application?

Answer:

The lower the frequency, the more advantageous it is, especially for IoT devices that are limited by power constraints. We aim for these devices to have an extended battery life. Lower frequencies offer the benefit of farther propagation at the same transmit power. As indicated in the aforementioned equation, a lower carrier frequency (fc) results in higher received power over the same distance.

We can utilize the 868/900 MHz band for license-free operations. It is also feasible to employ lower frequencies, specifically within the 100-200 MHz range, provided that we obtain the necessary permissions from the government to use these bands.

b) If the sensitivity of the signal that can be received by the satellite is —96 dBm, and the transmit power of the IoT device is 24 dBm with a transmit antenna gain of 6 dBi, what would be the antenna gain required at the satellite for the chosen frequency?

Answer: Let us calculate for 900 MHz, and 150 MHz. Thus, Fc = 900 MHz, Fc = 150 MHz

Pr > —100 dBm
Pt = 24 dBm
Gt = 6 dBi
D = 400, 000 meters
Fc = 900 MHz, 150 MHz
Alpha = 2

Gr = (to be estimated)

Either we can convert dBm to milliwatt, watt. Or we can use the logarithmic equivalent (2) above

For 900 MHz:

Step 1: $-96 = 24 + 6 + Gr + 20\log_{10}((0.333)/(4 * 3.14 * 400000))$
Step 2: -96 = 24 + 6 + Gr + 20 X -7.18
Step 3: -96 - 24 - 6 + (20 X 7.18) = Gr
Step 4: -96 - 24 - 6 + 143.572 = Gr
Step 5: 17.57 = Gr

For 150 MHz:

Step 1: $-96 = 24 + 6 + Gr + 20\log_{10}((2)/(4 * 3.14 * 400000))$
Step 2: -96 = 24 + 6 + Gr + 20 X -6.4
Step 3: -96 - 24 - 6 + (20 X 6.4) = Gr
Step 4: -96 - 24 - 6 + 128 = Gr
Step 5: 2 = Gr

c) What would be the antenna gain required if you instead employed a frequency of 13.56 MHz for communication? Why is this frequency not used for satellite communication between satellite and an IoT device? What are disadvantages?

Answer: The antenna size would be very large at such low frequency. It will impose challenges with form factor of both satellite and IoT device. Another challenge would be that a very small portion of 13.56 MHz band is available for license free communication.

For 13.56 MHz:

Step 1: $-96 = 24 + 6 + Gr + 20\log_{10}((22.1)/(4 * 3.14 * 400000))$
Step 2: $-96 = 24 + 6 + Gr + 20 \times -5.35$
Step 3: $-96 - 24 - 6 + (20 \times 5.35) = Gr$
Step 4: $-96 - 24 - 6 + 128 = Gr$
Step 5: $-19 = Gr$