CS4222/5422: Wireless Networking

Semester: 2022/2023

Tutorial 1 (Week 3, Starting 23rd of January 2023)

Question 1: What are the ISM frequency bands used for wireless communication? In residential and campus settings, such as National University of Singapore, which frequency bands support Wi-Fi communication? Lastly, do TV, and FM radio transmissions occur on ISM frequency bands?

Answer 1: Range of wireless frequencies reserved for Industrial, scientific, and medical purposes (ISM).

These frequencies include the 902-928 MHz band, the 2.4-2.4835 GHz band, and the 5.725-5.825 GHz band, among others. Because these frequencies are not allocated for specific uses, they are available for unlicensed use. Residential/college campus at NUS use the following: 2.4-2.4835 GHz, 5.725-5.825 GHz.

No, TV and FM radio does not occur on ISM bands, they have their own frequency allocation.

Question 2: Can you elaborate on the relationship between power consumption, data rate, and range in various wireless standards? If tasked with designing the following applications, what range and frequency of operation would you target for them? How would these choices impact the data rate?

Application	**Description**
Temperature sensor	This device allows measuring temperature inside the house. The sensor (temperature) readings are then wirelessly transmitted to a smartphone
Soil sensor	This device measures the humidity levels and quality of soil on farms, transmitting this information to a central base station located at the farm's center
IoT camera	Deployed in urban areas, this device captures images and short videos for surveillance purposes. The gathered information is wirelessly transmitted to the cloud for anomaly detection and processing

Answer sketch: We could roughly say:

- Lower the data rate, the higher the communication range. It helps improve the receiver sensitivity.
- Higher the data rate, more power is required to transmit the signal.
- Higher the range, more power is required to transmit the signal.
- Increasing data rate, or increasing range: Higher power consumption

Regarding applications:

Temperature sensor: Low data rate (small amounts of sensor information), short communication range, ISM frequency band, most likely 2.4 GHz frequency band for operation.

Soil sensor: Low data rate (small amounts of sensor information), moderate to high frequency range, likely frequency: Sub-GHz or Whitespace owing to better propagation characteristics

IoT camera: Medium to high data rate (sensor information could be large), moderate communication range (to base station or edge device), frequency: likely 2.4GHz, standards like WiFi, ZigBee or BLE.

Question 3: When designing a beacon device, such as an Apple AirTag or a Wiliot sticker, that is powered by small batteries or harvested energy from the environment, what wireless frequencies and data rate would you choose for the device to transmit small periodic information?

a) When the device transmits to short distances (few meters)
b) When the device transmit to large distances (hundreds of meters)

Possible frequencies for wireless communication: 30Hz – 40Hz, (ii) 30KHz – 40KHz, or (iii) 400MHz – 500MHz (iv) 800-950 MHz, (v) 2400-2480 MHz, (vi) 50GHz – 60GHz.

Answer sketch:

a) When transmitting over short distances, it is often beneficial to use higher frequencies, such as the 2.4 GHz band or 800-950 MHz However, we must also consider the power consumption and complexity of the underlying radio technology. Frequencies in the 50-60 GHz range may be too high, resulting in power-hungry radios. Additionally, links at these frequencies may be highly directional. It is also essential to consider the antenna size as well, as these devices are usually small. Therefore, using sufficiently higher frequencies, and allowing for smaller antenna sizes, is ideal. The 2.4 GHz ISM band is the most optimum.

b) For large distances, we would prefer lower frequencies. Considering that these devices are likely going to operate in ISM band, we may consider frequency band of 900 MHz

Question 4: A communication channel using a 20MHz spectrum in the range between 2.40GHz to 2.42GHz, has a signal to noise ratio of 63.

a) What is the Shannon capacity of the channel?
b) If the transmission is varied to use a 80MHz spectrum in the range between 5.00GHz to 5.08GHz (instead of 2.40GHz to 2.42GHz), explain why the throughput can drop even though the wireless frequency band used has increased from 20MHz to 80MHz (for the same distance between transmitter and receiver). The transmit power also remains the same as when 20 MHz of spectrum was used.

Answer sketch:

a) We can use the formula $C = B * \log2(1+ S/N)$ to estimate it to be 120 Megabit/second
b) The signal-to-noise ratio (S/N) decreases as the noise level increases with a wider bandwidth. Additionally, higher frequencies have poorer propagation characteristics, resulting in weaker signals (that is S) at the receiver. This can lead to a significant decrease in S/N, impacting the throughput

Question 5: There has been a growing interest in connecting Internet of Things (IoT) devices through a network of small satellites. One example of this is the service offered by SpaceX's Swarm. As a designer building these satellites, if the goal is to transmit small amounts of information from the satellite swarm to IoT devices on the ground, and given a distance of 300 kilometres between the satellite and IoT devices, your role is to determine the parameters for wireless communication.

a) What should be the antenna on the IoT device and satellite? What would be the ideal gain and type of the transmit and receive antenna?
b) What should be the maximum transmit power of the radio on the satellite to support a sufficient link budget? Please note that energy conservation on the satellite should also be considered.
c) Finally, what frequency would you want to use for communication? Can you estimate path loss?

Answer sketch:

a) We would want to use highly directional antennas on satellites and IoT device. We can use parabolic, Yagi or other such antennas. For these antennas, we can easily expect the transmit and receive gain to be 6-10 dBi

b) CubeSats (most like platform hosting these devices), are restricted to maximum transmit power of 1W (30 dBm) for establishing communication from devices in orbit to IoT devices on ground

c) We would ideally use sub-GHz frequency: 868, 900 MHz
We can calculate path loss: 128.8 dB
Services such as SpaceX swarm use frequency band < 200 MHz, keep in mind that lower frequencies have better propagation characteristics, and enables communication over distance of hundreds of kilometers.