2.1 Explain multihop communication and describe a scenario when it is useful

In multihop communication nodes are used between sender and receiver to work as repeater and such making it easier and more cost effective (because of a lower energy consumption, when sending over a large distance).
Using multihop communication is then profitable, when the data/information must be sent over a huge distant. This is because the more distance must be covered the more energy is required when only using one node as a repeater. If more nodes are used as repeater, therefore more hops are introduced, the energy consumption is not exploding as fast, when the distance gets longer, than when using only a few nodes.

2.2 What is the minimum time a sensor node has to go to sleep to make it a profitable operation with the following parameters?

a) t(down) = 3ms; t(up) = 3ms; I(active) = 15 mA; I(sleep) = 25 μA.
For an operation to be profitable it must be:

$$E_{saved} > E_{overhead}$$

, where:

$$\begin{aligned} E_{saved} &= (t_{event} - t_1) \cdot I_{active} - (\tau_{down} \cdot (I_{active} + I_{sleep})/2 + (t_{event} - t_1 - \tau_{down}) \cdot I_{sleep}) \\ E_{overhead} &= \tau_{up} \cdot (I_{active} + I_{sleep})/2 \end{aligned}$$

We search for the lowest $t_{event} - t_1 = T$.
With our imformation we get:

$$\begin{aligned} E_{overhead} &= 3ms \cdot (15mA + 25\mu A)/2 \\ &= 3ms \cdot (15025\mu A)/2 \\ &= 3ms \cdot 7512.5\mu A \\ &= 22537.5\mu A \cdot ms \end{aligned}$$

Therefore:

$$\begin{aligned} 22537.5\mu A \cdot ms &< T \cdot 15000\mu A - (3ms \cdot (15000\mu A + 25\mu A)/2 + (T - 3ms) \cdot 25\mu A) \\ &< 15000\mu A \cdot T - (22537.5\mu A \cdot ms + 25\mu A \cdot T - 75\mu A \cdot ms) \\ &< 15000\mu A \cdot T - 22537.5\mu A \cdot ms - 25\mu A \cdot T + 75\mu A \cdot ms \\ &< 14975\mu A \cdot T - 22462.5\mu A \cdot ms \\ 45000\mu A \cdot ms &< 14975\mu A \cdot T \\ T &> 3.005ms \end{aligned}$$

b) t(down) = 4.5ms; t(up) = 4.5ms; I(active) = 10 mA; I(sleep) = 15 μA.
For an operation to be profitable it must be:

$$E_{saved} > E_{overhead}$$

, where:

$$\begin{aligned} E_{saved} &= (t_{event} - t_1) \cdot I_{active} - (\tau_{down} \cdot (I_{active} + I_{sleep})/2 + (t_{event} - t_1 - \tau_{down}) \cdot I_{sleep}) \\ E_{overhead} &= \tau_{up} \cdot (I_{active} + I_{sleep})/2 \end{aligned}$$

We search for the lowest $t_{event} - t_1 = T$.
With our imformation we get:

$$\begin{aligned} E_{overhead} &= 4.5ms \cdot (10mA + 15\mu A)/2 \\ &= 4.5ms \cdot (10015\mu A)/2 \\ &= 4.5ms \cdot 5007.5\mu A \\ &= 22533.75\mu A \cdot ms \end{aligned}$$

Therefore:

$$\begin{aligned} 22533.75\mu A \cdot ms &< T \cdot 10000\mu A - (4.5ms \cdot (10000\mu A + 15\mu A)/2 + (T - 4.5ms) \cdot 15\mu A) \\ &< 10000\mu A \cdot T - (22533.75\mu A \cdot ms + 15\mu A \cdot T - 67.5\mu A \cdot ms) \\ &< 10000\mu A \cdot T - 22533.75\mu A \cdot ms - 15\mu A \cdot T + 67.5\mu A \cdot ms \\ &< 9985\mu A \cdot T - 22466.25\mu A \cdot ms \\ 45000\mu A \cdot ms &< 9985\mu A \cdot T \\ T &> 4.507ms \end{aligned}$$

2.3 Sensor node with following specifications

ERF32MG microcontroller: I(sleep) = 250 μA, I(busy)= 20 mA

CC1020 transceiver: I(send/receive)= 10 mA, data rate: 19,2 kbps

Measurement plus processing time: 10 ms

Every second a measurement is being made and processed imediately and send in one 96 byte packet to the sink. The voltage is 5V.

a) Compute the (average) power consumption, assuming that the node will instantly return to sleep mode after a duty cycle and no cost for state switching will occur.

$$\begin{aligned} \texttt{Microcontroller:} &\quad (10ms \cdot 20mA + 990ms \cdot 250\mu A)/1000ms = 0.4475mA \\ \texttt{Transceiver:} &\quad (96 \cdot 8bit/19.2kbps \cdot 10mA)/1000ms = 0.4mA \\ &\Rightarrow \texttt{Total of:} \quad 0.8575mA \\ &\Rightarrow P = U \cdot I = 5V \cdot 0.8475mA = 4.239mW \end{aligned}$$

On average the node consumes 4.239 mW of power.

b) The sensor node is powered by three 5V batteries with a parallel connection. Each battery has a capacity of 1000 mAh. Given the duty cycle (switching to sleeping mode) above and assuming ideal batteries, how long will a sensor node be able to operate? Assume a linear battery model without self-discharge.
From *a)* we know that the device uses 0.8475 mA, therfore:

$$t \;=\; 3000mAh/0.8475mA = 3539.82h \;=\; 147d\ 11h\ 9min$$