**EE5726: Embedded Sensor Networks**

**Assignment #03**

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**Problem 1**

**Scalability :**

Most modern Wireless Sensor Network (WSN) nodes are designed to perform more than a single task including communication, sensing, computing, etc. However, after deployment, the application may demand additional features to be incorporated into a node or even addition of nodes to enable more area coverage. At such a time, re-designing the complete system can be a huge time consuming effort and could cost a good deal of money. A node must therefore be able to perform it`s task irrespective of the relative state of another node or that of the network. This property of a WSN node to **meet its performance characteristic regardless of the size of the network is called scalability**.

In WSNs, the number of sensor nodes may be very large, exceeding thousands and in some cases millions of nodes. In these networks, scalability becomes a critical factor. One of the most common approcahe is to localize interactions among the communicating nodes by developing hierarchical structures and sharing the information collection and computing strategies. An effecient way to achieve this is to group the sensor nodes into clusters and allow shared access to the network.

**Energy Efficiency :**

A WSN node is equipped with one or more integrated sensors, embedded processors and the radio communication subsystem. Usually to keep their form factor small and allow portability, they are powered using batteries. Unlike traditional systems, these WSN`s are usually deployed in unattended remote locations where power may not be available. This makes charging of the batteries difficult. Energy scavenging is also a complicated and costly affair. As a result, *energy conservation* becomes of paramount importance in WSN`s to prolong the lifetime of sensor nodes and **efficiency of the WSN node** plays a very important role.

One logical approach to reduce energy consumption at a sensor node is to use low-power electronics. The integration of low-power chips in the design of sensor nodes is the most common way of achieving high levels of power efficiency. However, the communication subsystem consumes the most energy and unless the operations are not performed efficiently, the power consumption cannot be limited beyond a certain level. One must use *energy-aware communication protocols*. Frequent switching between different operation modes may also result in significant energy consumption. Limiting the number of transitions between sleep and active modes can lead to considerable energy saving. Taking all these factors while designing WSN`s is of key importance to increase the life of the system at large.

**Problem 2**

A wireless base station at a **height ($\mathbf{h_t}$) = 100 m** transmits at the unlicensed **carrier frequency ($\mathbf{f_c}$) = 5.775 GHz**. Its maximum **transmit power ($\mathbf{P_t}$) = 1 W**. **Base station antenna gain ($\mathbf{G_t}$) and receiver antenna gain ($\mathbf{G_r}$) are 4**.

**(1)** Receiver distance (d) = 1.6 km = 1600 m.
By applying Friis`s formula:

$$P_{\mathrm{r}} = \frac{P_{\mathrm{t}} \times G_{\mathrm{r}} \times G_{\mathrm{t}} \times \lambda^2}{(4\pi)^2 \times d^{\alpha} \times L} \tag{1}$$

Assume that the circuits are ideal and have no losses. Therefore, L = 1
$\alpha$ in free space = 2

and we know:

$$\lambda = \frac{c}{f} \tag{2}$$

therefore we get:

$$P_{\mathrm{r}} = \frac{P_{\mathrm{t}} \times G_{\mathrm{r}} \times G_{\mathrm{t}} \times c^2}{(4\pi)^2 \times d^2 \times f^2 \times L} \tag{3}$$

substituting the values:

$$P_{\mathrm{r}} = \frac{1 \times 4 \times 4 \times (3 \times 10^8)^2}{(4\pi)^2 \times 1600^2 \times (5.775 \times 10^9)^2} \tag{4}$$

$$P_{\mathrm{r}} = 1.06806 \times 10^{-10} W \tag{5}$$

therefore:

$$\mathbf{P_r = -69.714\ dBm} \tag{6}$$

Propagation delay of the signal = $\frac{d}{3 \times 10^8}$

$$= 1600/(3 \times 10^8)$$
$$= \mathbf{5333.34\ ns}$$

Hence, the calculated **received power is -69.714 dBm** and the **propagation delay is 5333.34 ns**.

**(2)** Receiver sensitivity is the lowest power level at which the receiver can detect an RF signal. The received power ($P_r$) is inversely proportional to the distance (d) between the transmitter and the receiver. Therefore, **the $\mathbf{P_r}$ will be the lowest when the receiver will be the farthest away from the source**.

Here, the sensitivity is **-91 dBm**.

$P_r$ = 10 log (P(mW))

-91 dBm = 10 log (P(mW))

P (mW) = $10^{-9.1}$

$P(mW) = 7.9432 \times 10^{-10}$

therefore: $P_r(W) = 7.9432 \times 10^{-13}$

From friis`s formula :

$$d^2 = \frac{P_t \times G_r \times G_t \times \lambda^2}{P_r \times (4\pi)^2 \times L} \tag{7}$$

Substituting the values from the given problem:
(I assume that the devices are in free space and ignore other sources of noise and intereference)

$$d^2 = \frac{1 \times 4 \times 4 \times (3 \times 10^8)^2}{(7.9432 \times 10^{-13}) \times (4\pi)^2 \times (5.775 \times 10^9)^2} \tag{8}$$

$$d^2 = 3.442 \times 10^8 \tag{9}$$

therefore

$$d = 18547m \tag{10}$$

This gives us : **d = 18.547 km**. Therefore, if the receiver is any farther than 18.547 km from the receiver, the signal would not be received.

**(3)** The breakpoint distance ($d_{bp}$) is given by : $\frac{4h_b h_m}{\lambda}$
Therefore,

$$d_{bp} = \frac{4 \times 100 \times 1.5 \times 5.775 \times 10^9}{3 \times 10^8} \tag{11}$$

$$d_{bp} = 11550m \tag{12}$$

therefore: $\mathbf{d_{bp} = 11.55}$ **km**

$L_p = P_t$ - $P_r$

$P_t$ = 1 W = 30 dBm

$P_r$ = 1 W = -91 dBm

therefore : $L_p$ = 30 + 91 dBm

$\mathbf{L_p = 121}$ **dBm**

According to the given rule : $\mathrm{L_p} = 38.1 + 25\ \log_{10}\mathrm{d}$ when $\mathrm{d} < \mathrm{d_{bp}}$
and

$\mathrm{L_p} = 38.1 + 25\ \log_{10}\mathrm{d_{bp}} + 45\ \log_{10}\frac{d}{d_{\mathrm{bp}}}$ when $\mathrm{d} \geq \mathrm{d_{bp}}$

Therefore, **case 1**:
consider $\mathrm{d} < \mathrm{d_{bp}}$ :

$$121 = 38.1 + 25log_{10}d \tag{13}$$

therefore:

$$log_{10}d = 3.316 \tag{14}$$

we have : **d = 2.07 km**

Therefore, **case 2**:
consider $\mathrm{d} \geq \mathrm{d_{bp}}$ :

$$121 = 38.1 + 25log_{10}d_{\mathrm{bp}} + 45log_{10}\frac{d}{d_{\mathrm{bp}}} \tag{15}$$

therefore:

$$82.9 = 25log_{10}11550 + 45log_{10}\frac{d}{11.55} \tag{16}$$

$$-18.664 = 45log_{10}\frac{d}{11550} \tag{17}$$

$log_{10}\frac{d}{11550} = -0.4147$
therefore : d = 4444.41 m
therefore **d = 4.44 km**

Since in both the conditions. we get $\mathrm{d} < \mathrm{d_{bp}}$, **case 1** holds true. Therefore, **the maximum distance that can be transmitted is 2.07 km**.