1

Motivation for a Network of Wireless Sensor Nodes

1.1 What is the difference between passive sensors and active sensor and can you name a few examples for each category (e.g. using Table 1.2 in the book)?

An active sensor requires external power, while a passive sensor can generate an output signal without the need for a power source such as a battery. Examples for active sensors include thermistors, strain gauges, infrared sensors, and Hall effect sensors. Examples for passive sensors include thermocouples, photodiodes, and microphones.

1.2 Consider a Wheatstone bridge circuit using a resistive temperature sensor R_x as shown in Figure 1.2 in the book. Further assume that $R_1 = 10\,\Omega$ and $R_3 = 20\,\Omega$. Assume that the current temperature is $80\,^\circ$F and $R_x(80) = 10\,\Omega$. You wish to calibrate the sensor such that the output voltage V_{OUT} is zero whenever the temperature is $80\,^\circ$F.

(a) What is the desired value of R_2?
The formula to compute V_{OUT} is $V_{OUT} = V_{CC} * (\frac{R_x}{R_3+R_x} - \frac{R_2}{R_1+R_2})$. Since V_{OUT} is supposed to be zero, the second term of this equation must be zero too. As a consequence, R_2 can be computed as $5\,\Omega$.

(b) What is the output voltage (as a function of the supply voltage) at temperature $90\,^\circ$F, when this increase in temperature leads to an increase in resistance of 20% for R_x?
Once the temperature increases to $90\,^\circ$F, the output voltage (using the same formula) will be $0.041\dot{6} * V_{CC}$.

1.3 As described in this chapter, using multiple communication hops instead of a single hop affects the overall energy consumption. Describe other advantages or disadvantages of multi-hop communications, e.g. in terms of performance (latency, throughput), reliability, and security.

Multi-hop communications have numerous effects on performance and node or network management approaches. For example, with respect to latency, multi-hop communications require that the same message is being transmitted and received several times. Each relay node incurs additional delays, e.g. for queuing the message. On the

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other hand, communications over short distances may often be more reliable, allowing a node to use a larger transmission rate (e.g. 11 Mbps instead of 1 Mbps for IEEE 802.11), reducing the communication time and overhead. Since the same message must be transmitted several times (and the limited channel capacity must be shared among the relays for both receiving and transmitting), the maximum achievable throughput will also suffer. Further, reliability can be affected in several aspects, e.g. shorter communication ranges may decrease the error probability, but having multiple nodes (relays) involved in the communication increases the risk of disruptions due to link or node failures. Finally, using multiple relay nodes provides an attacker with more opportunities to intercept or modify a transmission, thereby posing an increased security risk.

1.4 The relationship between the transmitted and the received power of an RF signal follows the inverse-square law (Equation (1.5)), i.e. power density and distance have a quadratic relationship. This can be used to justify multi-hop communication (instead of single-hop), i.e. energy can be preserved by transmitting packets over multiple hops at lower transmission power. Assume that a packet p must be send from a sender A to a receiver B. The energy necessary to directly transmit the packet can be expressed as the simplified formula $E_{AB} = d(A,B)^2 + c$, where $d(x,y)$ (or simply d in the remainder of this question) is the distance between two nodes x and y and c is a constant energy cost. Assume that you can turn this single-hop scenario into a multi-hop scenario by placing any number of equidistant relay nodes between A and B.

(a) Derive a formula to compute the required energy as a function of d and n, where d is the distance between nodes A and B and n is the number of relay nodes (i.e. $n = 0$ for the single-hop case).
$n = 0 : E = d^2 + c$,
$n = 1 : E = 2[(\frac{d}{2})^2 + c]$,
$n = 2 : E = 3[(\frac{d}{3})^2 + c]$, etc.
therefore: $E = (n+1)[(\frac{d}{n+1})^2 + c]$

(b) What is the optimal number of relay nodes to send p with the minimum amount of energy required and how much energy is consumed in this optimal case for a distance $d(A,B) = 10$ and (i) $c = 10$ and (ii) $c = 5$?
Table **??** shows the computation of the energy costs for (i) $c = 10$ and (ii) $c = 5$ for $0..7$ relays. In the first case, the minimum energy is obtained with $n = 2$ relays ($E = 63.\dot{3}$). In the second case, the energy costs for both $n = 3$ and $n = 4$ are 45, i.e., both scenarios (3 or 4 relays) would lead to the optimal case.

1.5 Name at least four techniques to reduce power consumption in wireless sensor networks.

Power management techniques can be found at various layers of a sensor node and sensor network design. Many processors can be operated at multiple frequencies and supply voltages using the DVS (dynamic voltage scaling) technique. Duty cycling refers to a device's ability to turn off the radio component when no transmissions are taking place or no incoming messages are expected. Further, the transmission power of wireless radios can be reduced, thereby limiting how far a signal can travel. Reduced transmission ranges can also lead to less interference and fewer collisions, therefore requiring fewer message

Table 1.1 Energy computation (Exercise 1.4)

Number of Relays	**Energy ($c = 10$)**	**Energy ($c = 5$)**
0	110	105
1	70	60
2	$63.\dot{3}$	$48.\dot{3}$
3	65	45
4	70	45
5	$76.\dot{6}$	$46.\dot{6}$
6	84.3	49.3
7	92.5	52.5

re-transmissions. The network layer is responsible for finding energy-efficient routes, e.g. when all nodes require the same amount of energy for receiving and transmitting a message, a route with the smallest number of relays (hops) is often the most energy-efficient route. Finally, in-network aggregation and elimination of redundant sensor data can reduce the amount of communication needed by sensor nodes, thereby also reducing the energy overheads.

2

Application

2.1 Most applications in wireless sensor networks extract time and frequency domain features to detect interesting events. Define the following features:

(a) Autocorrelation function

The autocorrelation of a random process describes the correlation between the values of the process at different points in time. The correlation can be expressed as a function of the two times or of the time difference. Let X be some repeatable process and i be some point in time after the start of that process – i may be an integer for a discrete-time process or a real number for a continuous-time process – and x_i is the value measured at time i. Furthermore, assume that the process has a mean value of μ_i and a variance of σ_i^2 for all times i. Then the autocorrelation between any two times j and k is:

$$R(j,k) = \frac{E[(x_j - \mu_i)(x_k) - \mu_i]}{\sigma_j \sigma_k} \tag{2.1}$$

(b) Correlation coefficients The correlation coefficients of two discrete sequences X and Y is a measure of the existence of a linear dependency between the sequences. It takes the quotients of the covariance and variance of the individual sequences into account:

$$CC(XY) = \frac{COV(X,Y)}{\sqrt{VAR(X)VAR(Y)}} \tag{2.2}$$

where:
$COV(X,Y) = \frac{1}{N}\sum_{i=1}^{N}\left(x_i - \bar{X}\right)^2\left(y_i - \bar{Y}\right)^2$ and,
$VAR(X) = \frac{1}{N}\sum_{i=1}^{N}\left(x_i - \bar{X}\right)^2$.

(c) Cross-correlation function

it is an indication of the existence of a correlation between two time series measurements $s_1(t)$ and $s_2(t)$, where s_1 and s_2 may represent either the same type of movement measured at different locations, or a single movement measured at the same location but at different times. In case $s_2(t)$ represents $s_1(t+\tau)$, where τ is a specified time lag, the two variables are usually not statistically independent, and large cross correlations between s_1 and s_2 can result. Mathematically, the cross correlation, XC, is described as follows:

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