Energy per pair = $Energy_{Tx}$ + $Energy_{Rx}$

Total Energy consumption = n* Energy per pair = n *($Energy_{Tx}$ + $Energy_{Rx}$) nJ

(d) Repeat

The requirement to combine and compress the volume of data is called aggregation.

Energy transmitted per node: $(0.5+100)*B + 100*B*D^2$

Energy received per node: $(0.5+100)*B$

Energy per pair = $Energy_{Tx}$ + $Energy_{Rx}$

Total Energy consumption = n* Energy per pair = n *($Energy_{Tx}$ + $Energy_{Rx}$) nJ

If it is every alternate frame, then total energy per pair = n/2 * Energy per pair

With aggregation:

Energy transmitted per node: $(5+0.5+100)*B + 100*B*D^2$

Energy received per node: $(5+0.5+100)*B$

Energy per pair = $Energy_{Tx}$ + $Energy_{Rx}$

Total Energy consumption = n* Energy per pair = n *($Energy_{Tx}$ + $Energy_{Rx}$) nJ

Frames	*Energy per node*	*Frames*	*Energy per node*
1	E_T	9	E_T
2	E_T	10	E_T
3	E_T	11	E_T
4	E_T	12	E_T
5	E_T	13	E_T
6	E_T	14	E_T
7	E_T	15	E_T
8	$E_{T'}$	16	$E_{T''}$

Total number of nodes = 10*8 = 80 nodes.
Aggregation done by CH every 8 frames and CH to base station every 16 frames.

Energy transmitted per node: $(5+0.5+100)*B + 1000*B*D^2$

Energy received per node: $(5+0.5+100)*B$

Energy per pair $E_{T''}$ = $Energy_{Tx}$ + $Energy_{Rx}$

Total Energy consumption = n* Energy per pair = n *($Energy_{Tx}$ + $Energy_{Rx}$) nJ

The aggregation of data could be spatial or temporal. So data could be aggregated from several sensors at a time or data can be obtained from a single sensor over a period of time and merged together before it is sent out.

Problem 14.3

It's a new characteristic in ad-hoc sensor networks where thousands of sensors are deployed in a specific geographic randomly without the considering the location factor. After deployment, the sensors are to self-organize themselves to form a network of their own. The formation of the network will determine the life of the network and the quality of data transmission.

https://m.scirp.org/papers/1149

Problem 14.4

If the number of sensor nodes are doubled, the energy consumption is doubled, however since the performance improves the frame error rate will decrease hence eventually the energy consumption will be reduced.
The network energy is relevant with both frame error rate and the sending power of data transmission. The larger the sending power, the lower the frame error rate, the lower the frame error rate more energy will be saved, hence the frame error rate and the sending power restrict each other and network energy consumption is better balanced under a certain balance of both.

Problem 14.5

If the number of sensor nodes are halved, initially total energy consumption of the network will be halved since it depends on the number of nodes. However the frame error rate will increase hence the energy consumption will eventually increase.

Problem 14.6

If the cluster members are divided into two groups of four sensor and they take turns going to sleep-awake modes then the energy cost is minimized. The energy cost is Rx+Tx + Listen. If the channel periodically wakes up and sleeps in synchronization with other nodes then performance can be optimized. The effective lifetime of the sensor network will also be enhanced.

A specific strategy for sleep awake mode consists of dividing the nodes into clusters. The head of each cluster defines the TDMA schedule hence there is no further collision in transmission of data by the various different sensors. This removes the requirement for CSMA/CA techniques.

Problem 14.7

The data frames for nodes A, B, C and D are time slotted. Communication within the data nodes are with the TDMA format. The teen protocol which is known as the threshold sensitive energy efficient sensor network protocol . It has a hard threshold (HT) for the specific sensed attribute. It is developed for reactive networks. When the absolute value of the specific sensed attribute goes above the HT value, the node will turn on the transmitter and report it to the cluster head. The soft threshold (ST), a minute change in the sensed attribute will trigger this threshold and hence the transmitter will start transmitting. Details include, the following when the node switches on its transmitter and send the sensed data it also stores the sensed data in the Sensed Value (SV) variable. The ST is triggered when the current value of the sensed attribute is equal to or greater than the SV.

Advantages :

- Time critical data reaches the user almost instantaneously, hence TEEN is suitable for time critical applications.
- Message transmission consumes more energy than data sensing, hence although the network senses continuously the energy consumption in this scheme is much less than in proactive networks since data transmission is done less frequently.

Problem 14.8

(a) $2x\ E_T$
(b) $4xE_{T''}$

Problem 14.9

Hierarchical clustering model

Problem 14.10

The number of nodes * Energy transmission per node

Problem 14.11

Flat clustering model

Problem 14.12

The APTEEN protocol is utilized for applications where the user wants time critical data and also wants to query the network for analysis of conditions other than collecting time critical data.

The protocol provides two advantages over other protocols: it provides time critical data and an overview of the network at periodic intervals.

Combining the features of reactive and proactive networks, it's a hybrid network.

Similar to TEEN protocol, except the Adaptive TEEN does the following once the cluster heads are decided.

- Broadcasts: Periodicity, Attributes, Thresholds, Schedule and Count Time

  If a node does not transmit data for a time equal to the count time, it is forced to sense and transmit data at a much longer interval irrespective of the sensed value of the attribute, hence even if the ST or HT values have not been reached.

- Collisions can occur when the sensors near each other fall into the same cluster with the same cluster head. They have similar data and try to transmit data simultaneously. In this situation, a TDMA schedule is used and each node in the cluster is assigned a transmission slot.

The flexibility includes allowing the user to set the CT interval and the threshold values for the attributes. It can change the count time as well as the threshold values. It can control energy consumption and support both proactive and reactive behavior of the sensor network. It is time critical and provides sends periodic data of the complete network. The main drawback is the additional complexity required to implement the threshold functions and count time.

Problem 14.13

A wireless sensor transmitter/receiver range is 2m and size of building is 50m x 50m with the height of 25m.

A flat topology can be utilized.

The triangular topology would be optimal in this situation.

Problem 14.17

The sensor network needs a protocol that is application specific however it is also generic enough to be data centric. Traditional routing protocols between any two devices for WANET and MANET is not well suited for sensor networks.

Problem 14.18

The query is disseminated (flooded) throughout the network from the base station to the sensor nodes in a step by step manner from 1 to 4 steps. The gradients are setup to indicate the path to be used by each sensor node to the base station. This utilizes less power compared to transmitting query from the base station to all the sensors at a high power level. The gradients are set up to indicate the path to be used by each sensor node to the base station. It identifies the path to be used by each sensor node to the base station.

This is suitable when the base station does not have enough power to broadcast the query to all the sensors in a single high power transmission and hence needs to utilize multi-hop broadcasting.

The disadvantage is that it cannot fully exploit data aggregation among adjacent nodes.

Problem 14.19

Spatial or temporal aggregation of data. At a given time, the data could be aggregated from several sensors or over time it can be collected from a single sensor. Key characteristics include time involved in the aggregation process and the accuracy of the data. This is a design trade-offs and further research is being conducted in this area.

Problem 14.20

Yes, ideally you want to synchronize the two clusters of sensor nodes.

Problem 14.21

Yes.

Problem 14.22

Its possible

Sensing area of $1/2\text{piRadius}^2$

Problem 14.23

Yes if the shortest path information is retained.

Problem 14.24

Gossip based ad hoc routing. The concept includes a gossiping probability. The gossiping protocol is very simple. A source sends the route request with probability 1, when a node first receives a route request with probability p it broadcasts the request to its neighbors with the probability of 1-p. Hence 1-p discards the request. If the node receives the same route request again, it is discarded. Hence each nodes forwards a message with some probability which reduces the overhead of the routing protocol. Gossiping exhibits bimodal behavior for large networks. For a probability of 06. To 0.8 almost every node get the message in almost every execution, hence for large networks it utilizes upto 35% fewer messages than flooding. Hence it displays improved performance. (Agrawal)

Problem 14.25

Direct diffusion based flat architecture is suitable for consistent and persistent queries where the requesting nodes is expecting data that satisfies a query for some duration or for power conservative applications.

Cluster based sensor network is not suitable for wireless sensor networks. Extensive effort is required to maintain the clusters. The sensor nodes do not have much mobility. The cluster based routing protocol divides the network nodes into a number of overlapping or disjoint two hop diameter clusters in a distributed manner.

Problem 14.26

User queries can be categorized into historical query, one-time query and persistent query. The historical query is utilized for analysis of historical data stored in the base station . The one time query provides an overview in a specific point of time of the network. The persistent query is used to monitor a network over a time interval with respect to some time parameters.

Problem 14.27

Tbd MANET simulator

Problem 14.28

Application centric question.

Problem 14.29

Various automobile sensors include flow sensor, tire pressure sensor, light sensor, acceleration sensor, temperature sensor, heart frequency and arterial pressure. (Jorge Tavares, 2008)

Problem 14.30

Inside a vehicle, the Controller area network (CAN) is the most widespread system of communication between sensor nodes (SNs) inside a vehicle with wired connections. This wired connection is scalable nor is it flexible. Hence wireless links are required. RFID, Zigbee are good examples of protocols used for the design of intra vehicle wireless sensor networks. (IVWSNs) (Rahman)

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