Problems and Solutions (Chapter 13)

1. What are the differences between cellular and ad hoc networks?

   [Solution]

   Cellular network model supports the needs of wireless communication by installing BSs as access points. Communications between two mobile nodes completely rely on the wired backbone and the fixed base stations. In an ad hoc network, no such infrastructure exists and the network topology may change dynamically in an unpredictable manner since nodes are free to move in an arbitry direction with a random speed.

2. Why is it not possible to use circuit switching in ad hoc networks?

   [Solution]

   Ad hoc networks are basically peer-to-peer multi-hop mobile wireless networks where information packets are transmitted in a store-and-forward manner from a source to an arbitrary destination. It is not possible to have all nodes within each other's radio range. Only few nodes are within each other's radio range. First path from the a source to a destination could be determined on-the-fly and even after that, circuit switching requires message receipt and transmission by each intermediate node along the path. This cannot be supported by current ad hoc network antenna technology. Therefore, it is not possible to use circuit switching in ad hoc networks.

3. A given ad hoc network consists of 100 nodes and the mobility of the nodes is such that every one second, two existing radio connections are broken, while two new radio links are established. Assuming each node is connected to exactly four adjacent nodes. Find the total number of communications links in the network.

   [Solution]

   Number of link connections $= 100 * 4 = 400$. As each link is connected to two nodes, the number of links $400/2 = 200$.

4. In Problem 13.3, if the updated message is sent every 5 seconds, what is the upper limit on the number of messages initiated periodically if a table-driven routing protocol is to be used? Explain clearly.

   [Solution]

   Because every one second, two existing connection are broken, two new radio links are established, so, every one second, there are four updating message, if the updated message is sent every 5 seconds, the upper limit on the number of messages initiated is $4 * 5 = 20$.

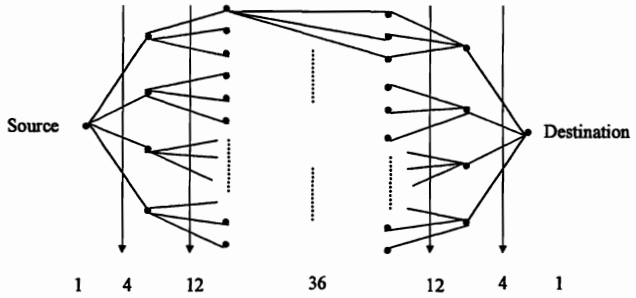
5. In Problem 13.4, if the destination node is located at 5 hops apart from a given source node, what is the maximum possible value of:

(a) Number of alternate paths of length of 5 hops?

(b) Alternate disjoint paths of length 5 hops?

[Solution]

(a) Alternate paths means a source node S can take A-B-C to destination D, it also can take M-L-N to destination D if the formal link fails. If the destination node is located at 5 hops apart from a given source node, every node is connected to exactly 4 adjacent node, therefore, source can connect with four adjacent node, among these four adjacent nodes, every node mostly can connect with another 3 nodes, then from 4 nodes arrive to destination. Therefore, there would be $4*3*3*1*1 = 36$ alternate paths (maximum).

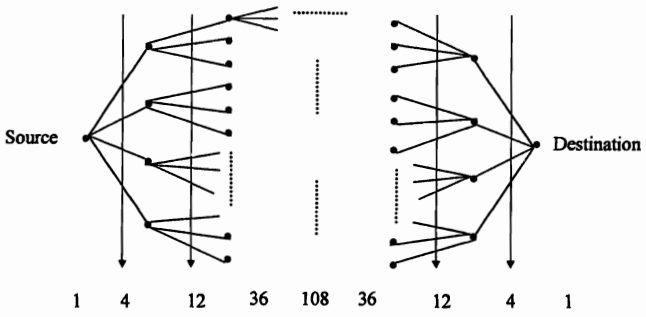


(b) For disjointness, no intermediate node should be common among the paths. One simple way is to have a unique path between 12 nodes after 2 links from either source or destination, giving $4*3*1*4 = 48$ disjoint paths (maximum).

6. Repeat Problem 13.5, if the distance is changed to 8 hops.

[Solution]

If the distance is change to 8 hops, then the maximum number of possible alternate paths would be $1*4*3*3*3*1*1*1*1 = 108$ and all these are disjoint.



7. A snapshot of an ad hoc network is shown in the figure.

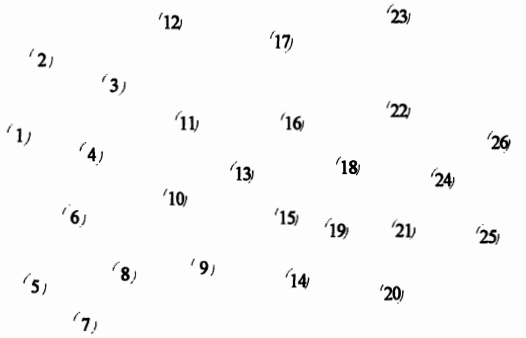


Figure for problem 13.7

describe briefly the process taken to

(a) How can you create a route from the source node 6 to the destination node 23 using DSR algorithm?

(b) Repeat part (a) using TORA routing.

(c) What changes would you do in part (a) if you use the AODV protocol?

[Solution]

(a) By using DSR algorithm to create a route from 6 to 23, node 6 at first checks its route cache to determine whether it already has a route to the destination 23, if it has, it will use this route. If it does not have such a route, it initiates route discovery by broadcasting a route request packet. This route request contains the address of node 23. A reply is generated when the route request reaches either node 23, or an intermediate node whose route cache contains an unexpired route to the destination.

(b) For TORA, when node 6 needs a route to node 23, node 6 broadcasts a query packet containing the address of node 23. This packet propagates through network until it reaches either node 23, or a node having a route to the node 23. The recipient of the query then broadcasts an update packet listing its height with respect to node 23.when this packet propagates through the network; each node that receives the update sets its height to a value greater than the height of the neighbor from which the update message has been received.

(c) For AODV, node 6 broadcasts a route request packet (RREQ) to its neighbors, which then forwards the request to their neighbors, and so on, until either node 23 or a node with "fresh enough" route to node 23 is located. The main difference between the DSR and AODV

is that DSR uses source routing and AODV uses forwarding tables at each node. During the process of forwarding the RREQ, nodes record in their route tables the address of the neighbor from which the first copy of the broadcast packet is received, thereby establishing a reverse path.

8. How does signal stability affect the route in Problem 13.7?

   [Solution]

   SSR chooses the routes that have "stronger" connectivity period. Therefore, if one route from node 6 to node 23 such $6-4-3-12-17-23$ exists, but its connectivity time continues for only 1 second then this route is disconnected. IF another route, like $6-4-10-11-16-18-22-23$, has its connectivity time is 10 seconds, we should select the latter route. This principle is employed for all algorithms.

9. Assuming that the location of the destination node 23 is known to be located in the north-east direction, what changes do you need to do in determining a route in Problem 7? Explain clearly.

   [Solution]

   If the node 23 is known to be located in the north-east direction, route request flood's scope would be limited, for example, when node 6 flood its packet, it would send packet to nodes 4 and 8, need not send packet to nodes 5 and 7 as node 23 is in the north-east direction.

10. In ad hoc networks, it is sometimes desirable to transmit packets of a single message using multiple paths.

    (a) Can you think of any specific reasons for the same?

    (b) If you need to employ two alternate paths, how would you determine that in Problem 7 using DSR?

    [Solution]

    (a) For wireless ad hoc networks the most natural way of finding a path is broadcasting since radios are based on omni-directional antennas. However, sometimes node or link failure could happen and, by using alternate paths, data can be easily rerouted. When a node cannot forward a packet due to a broken link, it will send a route error packet (RERR) to the source. The source can then initiate a new route discovery to find a new route to the destination. Network reliability is most crucial for performance critical networks; route diversity offers redundancy via alternate paths.

    (b) If we need to employ alternate paths, for Problem 7, such as DSR, when a node gets a packet that it needs to send on a particular link, if it knows that the link is down, it looks up the cache and sends on an alternate route; but doesn't start a new round of route discovery.

11. Consider an ad hoc network where communication (message or packet transfer) is to take place from node X to node Y. The route has already been established and a data packet is to be transferred over n hops. To transfer the packet, the kth node uses the following medium access protocol:

    - It waits for time $t(k)$ after which the channel becomes free. $t(k) = k\alpha$ time units.
    - It transfers the data packet to the next hop. This takes 'α' time units.
    - It receives an acknowledgement. This takes another '$\alpha/2$' time units.

    The time $t(k)$ before the kth node actually transmits the data packet is given by $t(k) = k\alpha$ time units.

    (a) Find an expression for time taken for the data to cover 'n' hops, i.e., from node 1 to node $n+1$.

    (b) If the time taken to travers 'n' hops is $T = 2n\sqrt{n\alpha}$, what is the value of 'n'?

    [Solution]

    (a) For node I, it waits for time $t(i) = i * \alpha$ time units, then it transfers the data packet to node $(i+1)$, this takes α time units. Then it waits for acknowledgement, which takes $\alpha/2$ time units. Therefore : from node 1 to node $n+1$, there would be

    $$(\alpha+\alpha+\frac{\alpha}{2})+(2\alpha+\alpha+\frac{\alpha}{2})+(3\alpha+\alpha+\frac{\alpha}{2})+\ldots\ldots(n\alpha+\alpha+\frac{\alpha}{2}) = (\frac{n^2}{2}+2n)\alpha$$

    (b) $n = 4$

12. Illustrate how multipath routing can be done between nodes a and 26 of Problem 13.7. Which multipath routing technique is beneficial and why? Explan clearly.

    [Solution]

    Nodes 4 and 2 are the only direct neighbors of node 1 (and 22 and 24 for node 26). Thus, the total number of distinct multi-paths cannot be more than two. However, there can be several overlapping multi-paths from 1 to 26. Two non-overlapping paths are:

    1-2-3-12-17-23-22-26

    and

    1-4-10-13-15-19-21-24-26

    There can be several other non-distinct multi-paths.

A multipath algorithm that can be used in the given scenario is Fresnel Zone Based Routing. The primary idea behind this routing protocol is that the source as well as the intermediate nodes take part in multi-path forwarding. Thus, the number of paths is not decided only at the source since more paths may arise at the intermediate nodes. The reason this algorithm is aptly suited for the given scenario is because the source has only two neighbors and cannot compute more than two distinct multipaths to the destination. The intermediate nodes can decide on more multipaths and forward the traffic accordingly.

13. What is meant by piggybacking and what are the advantages? Explain clearly.

    [Solution]

    Piggybacking means sending the specific message using the already defined the message, such as RTS, CTS. It includes the specific message in the packet of RTS and CTS, no need to specify the separate packet. It reduces the complexity of protocol..

14. What are the implications of using CDMA in an ad hoc network? Explain in detail.

    [Solution]

    Following are the implications of using CDMA in an ad hoc network:

    (a) Modulation using a code is relatively complex and consumed energy could make it less attractive for ad hoc networks.

    (b) Due to mobility, two or more nodes having the same code may move into the same region.

    (c) Code distribution is a centralized function and an ad hoc network will have the addition task of distributing this centralized task.

15. What are the advantages and disadvantages of reactive and proactive protocols? Which one would you prefer and why? Explain with specific conditions.

    [Solution]

    Reactive protocols:

    Advantages:

    (a) The routing protocol is active only when data is required to be transmitted between nodes.

    (b) Storage of all routes not required.

    Disadvantages:

    (a) Latency involved when data needs to be transmitted due to non-availability of routes

Useful Scenarios: Light traffic scenarios, where proactive protocols would incur high overhead. Attractive for large networks.

Proactive protocols:

Advantages:

(a) Data does not face any latency due to route updates and can be sent fast.

Disadvantages:

(a) Protocol is active at all times, even when data is not being transmitted

(b) Storage of all routes required.

Useful Scenarios: Heavy traffic scenarios. Attractive for small networks.

16. What are the similarities and differences between ad hoc networks and sensor networks? Explain clearly.

[Solution]

Ad hoc networks have characteristics of band width-constrained, energy-constrained operation. Wireless sensor networks also have such characteristics. While, ad hoc networks have dynamic topologies, nodes are free to move, the mobility of nodes in a sensor network is very limited. Wireless sensor networks are "data centric", unlike traditional networks where data is requested from a specific node. A wireless sensor network is a collection of tiny disposable and low power devices. The routing protocols proposed for all the traditional networks are point-to point and so these protocols are not well suited for wireless sensor networks.

17. In a sensor network, the energy consumed by different functions by a sensor, is as follows

Mode	Energy Consumed (in nJ/bit)
Sleeping mode	0
Sensing or idle mode	0.5
Aggregation	5
Communication to Cluster Head	100
Cluster Head to BS	1000

Assume the total number of nodes as P, number of non-cluster nodes as n, the number of cluster heads to be m and the frame size to be B bits.

(a) Find the power consumption, during a frame time period if sensing and communication is done during every frame, assuming other half nodes are sleeping at that time.

(b) Find the power consumption in the idle frame when sensing and communication to CH is done in every alternate frame. Remember that power is consumed even in sleeping mode of the cycles, when sensing is not carried out.

(c) Find the total power consumption in different frames if sensing is done every alternate cycle, while transmission to CH is done every fourth frame.

(d) Repeat part (b) if there are 10 clusters, with each cluster consisting of 8 sensor nodes and aggregation is done by CH every 8 frames while CH to base station communication takes place every 16-frames.

[Solution]

In a sensor network, the energy consumed by different functions by a sensor, is as follows:

- – Sleeping mode is 0.
  – Sensing mode is 0.5.
  – Aggregation is 5.
  – Communication to cluster head is 100.
  – Cluster head to BS is 1000.
  – Energy consumed is in nJ/bit.

Assume total number of nodes is P.

Assume number of non-cluster nodes is N.

Assume number of cluster heads is M.

Assume size of frame in bits is B.

(a) Sensing and communication is done during every frame, assuming other half nodes are sleeping at that time. Assuming that half of both cluster and non-cluster nodes. Therefore, the power consumption during a frame time period is
$0.5 * (N + M) * 0.5 + 5 * 0.5 * M + (0.5 * N * 100 + 1000 * M) * B$
$= 0.25 * N + 2.75 * M + 50 * N * B + 1000 * M * B.$

(b) Sensing and communication to CH is done in every alternate frame. Remember that power is consumed even in sleeping mode of the cycles, when sensing is not carried out. Therefore, the power consumption in the idle frame is $5 * (N + M)$.

(c) There are 4 types of frames

- Idle frames: $5 * (N + M)$ or 500 nJ
- Sensing frames: $0.5 * (N + M)$ or 50 nJ (When the sensing and transmission do not coincide)
- Transmission frames: $100 * N * B$ (When the sensing and transmission do not coincide)

- Sensing and transmission frames: $0.5*(N+M)+100*(N+M)$ (When the sensing and transmission do coincide)

(d) There are 4 kinds of sensing frames

- Sensing frames: $0.5*(N+M)$ or 40 nJ (When the sensing, aggregation and transmission do not happen)
- Sensing frames with aggregation: $0.5*M+5*M=5.5*M$ or 27.5 nJ (Only the cluster heads before sending to BS)
- Sensing frames with communication to BS: $0.5*M+1000*M$ or 5002.5 nJ
- Sensing frames with aggregation and communication to BS: $0.5*M+1000*M+\%*M*B$ or 10005 nJ $+50*B$ nJ.

18. Assuming that CDMA/TDMA is used for each cluster of Problem 16 (d). Can you come up with time-slot schedule for each cluster of the sensor network, when TEEN protocol is to be used? Assume that two levels of clustering is present. Remembering that CHs need to communicate with the base station as well, using a different CDMA code.

    [Solution]

    The transmission of inter-cluster nodes uses TDMA with different time-slots. The transmission from cluster head to base station use CDMA. When TEEN protocol is used, if the thresholds are not reached, the nodes will never communicate, the user will not get any data from the network at all. Each node waits for its time-slot to transmit if it senses the changes of data. Cluster head transmit data to BS when receiving data, and finish aggregation.

19. What changes you need to make in Problem 13.18, if APTEEN protocol need to be used?

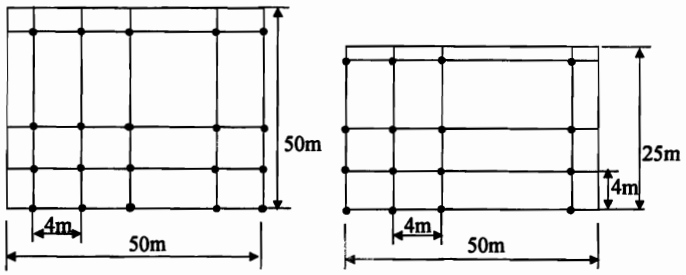
    [Solution]

    Using APTEEN protocol, the node not only sends data periodically, they also respond to sudden changes in attribute values. The maximum time period between two successive reports sent by a node need to maintained.

20. A wireless sensor has a transmitter/receiver range of 2 m and many such sensors need to be installed in a nuclear plant building of size 50 m $\times$ 50 m with the height of 25 m. Can you think of an efficient arrangement of the sensor arrays? Explain clearly.

    [Solution]

    We arrange the sensors as showned in the following Figure where we would have complete coverage of all of the nuclear plant building sensing all kinds of attributes. The distance between two adjacent sensors is 4 m.



Solution 13.20

The total sensors we need is

$$\left(\frac{50-2}{4}+1\right)\left(\frac{50-2}{4}+1\right)\left(\left\lceil\frac{25}{4}\right\rceil+2\right)=1352$$

21. What will be the impact in Problem 19, if the sensor range could be increased to 10 m?

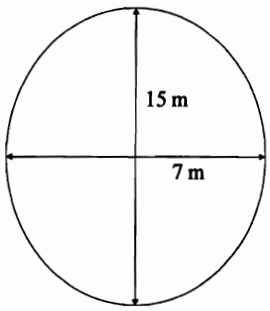
[Solution]

The distance between two adjacent sensors is 10 m. The total sensors we need is

$$\left(\frac{50}{10}+1\right)\left(\frac{50}{10}+1\right)\left(\left\lceil\frac{25}{10}\right\rceil+2\right)=144$$

Therefore, the arrangement will be sparser and distributed all inside to achieve complete coverage.

22. Repeat Problem 19, if it is to be done for a 56 m long airplane, if its cross-section is represented as shown in the figure below.



Problem 13.22

[Solution]

For airplane, we cannot arrange the sensors in everywhere. That is impractical. We place the sensors on the inside wall of the airplane keeping a distance from sentive electronics and makes sure that the channels used or not interfere with the channels used by the airplane to contact the airport.

23. Repeat Problem 13.19, if it is to be done for a lake of size 250 m length × 50 m width × 5 m deep if biosensors are to be installed to monitor pollutant level if the range of each sensor is 0.5 m.

    [Solution]

    For a lake of size 250 m × 50 m × 5 m, the sensors can be arranged the same way as that Problem 17. Therefore, the total sensors we need is We arrange the biosensors distributive in the lake. Therefore, the total number of sensor nodes is

$$\left(\frac{250}{1}+1\right)\left(\frac{50}{1}+1\right)\left(\frac{5}{1}+1\right)=76806$$

24. Why do you use "data-centric" approach in a sensor network?

    [Solution]

    Data centric approach is used in sensor networks to save energy with the help of aggregation. In this approach instead of the traditional address centric approach we follow the data centric approach for establishing the routes.

25. What are the advantages and limitations of a "directed diffusion" approach in a sensor network? Explain clearly.

    [Solution]

    Directed Diffusion helps in routing the data towards the aggregator nodes. All data is routed towards a single path so that similar and relevant data can be grouped and remove redundant data there by saving energy. Directed diffusion is for flat network topology.

26. A clustering approach has been suggested to locally collect and "aggregate" information in a sensor network. What kind of aggregation is desirable?

    [Solution]

    The aggregation should have the following properties:

    (a) Data has high correlation and the aggregator can discard most of the results without loss of information

    (b) Obtained data should have the property that the information represents a temporal spanning as well.

    (c) The aggregators collecting information from the lower level aggregators can also discard some information

27. Can the past response location of a query be helpful in limiting the flooding area? Explain clearly.

    [Solution]

The answer is divided in two cases.

Case1: There is a spatio-temporal correlation in the response behavior of the query.

In this case, let the response at a specified location X of the sensor network at time T be $r(X,\ T)$. Then at time $T+t$, the response at that location is $r(X,\ T+t)$. If the following holds:

$$\frac{\partial r}{\partial X} \approx \frac{\partial r}{\partial T},$$

then the flooding area can be limited to a specified region as the response location can be found within a limited region. The region is decided by the difference between the LHS and RHS of the above relation. Examples of such cases are temperature monitoring, gas pressure monitoring etc.

Case 2: There is no correlation between the responses in a region.

In this case, the response has no defined spatial region and the query cannot be limited to a region. Examples are random events like random atmospheric particle detection, etc.

28. From your favorite website, find what is meant by "gossiping-based routing". What are the advantages and limitations of such an approach? Expain clearly.

    [Solution]

    To reduce the overhead incurred due to routing messages (which are mostly wasteful), a gossip based protocol proposes to send the routing messages with some probability. Messages die out when spanned over a large region, thus limiting the overhead involved.

    Advantages: Considerably reduces message overhead due to routing messages

    Limitations: Performance might degrade in highly mobile or smaller networks. Also, the value of the transmission probability has to be suitably fixed to ensure proper network functionality.

29. In a sensor network, energy consumption is one of the major constraints. Keeping this in mind, what factors would one consider when designing security scheme for such networks? Explain.

    [Solution]

    Following are the factors that have to be kept in mind:

    (a) The scheme should not involve expensive operations like modular exponentiation etc.

    (b) Public key and signature schemes should be avoided.

    (c) Hash functions (even though there is no one-to-one correspondence) are non-expensive and should be used as much as possible

(d) Message overhead should be kept to the minimal

(e) The protocol should have a very small state diagram in order to limit the code used for its implementation.

30. How can you provide security in an ad hoc network? What are different possible schemes and their relative advantages?

[Solution]

Security in ad hoc networks has the following goals:

(a) The key distribution cannot rely on a central server and should be distributed

(b) Group formation should avoid centralized control

(c) Protocol should be highly resistant to Man-in-the-Middle attacks

(d) Strong resistant to Distributed Denial of Service attacks

Few possible schemes are as follows:

(a) Distributed trust server using threshold cryptography.

(b) Distributed group formation using polynomial based solutions

(c) Use of bivariate polynomials in which any two nodes can compute pairwise symmetric keys.

(d) Strong signed routing schemes between pair of nodes constituting a link of the path.

(e) Use of intrusion prevention to detect malicious DDoS launcher.