Lecture (08, 09)
Routing in Switched Networks

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Agenda

- Routing protocols
  - Fixed
  - Flooding
  - Random
  - Adaptive
- ARPANET Routing Strategies

Routing protocols

- A key design issue in switched networks, including packet-switching, frame relay, and ATM networks, and with internets, is that of routing.
- generally, more than one route is possible.
- Thus, a routing function must be performed to find the best possible route.

characteristics required:

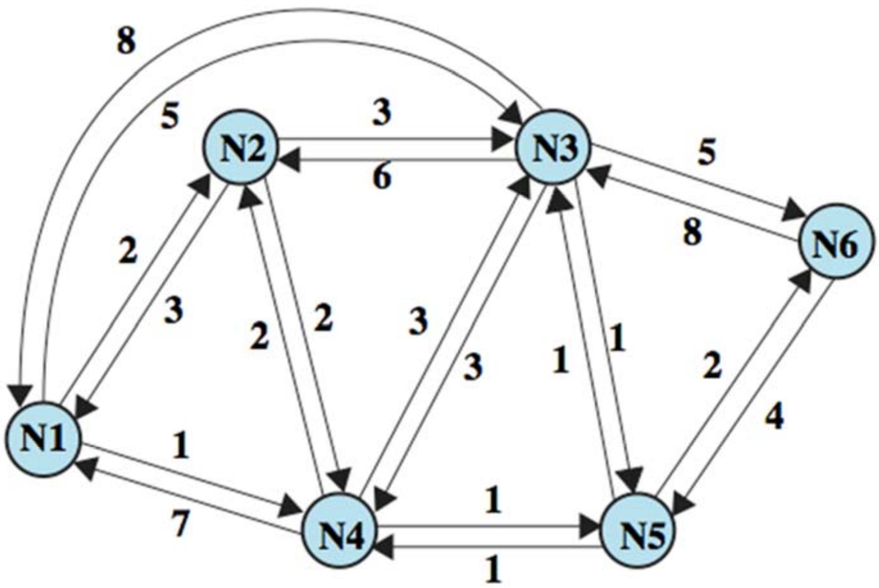
- correctness
- simplicity
- Robustness: ability of the network to deliver packets via localized failures and overloads.
- Stability
- Fairness x
- efficiency
- optimality

Some performance criteria may give higher priority to the exchange of packets between nearby stations compared to an exchange between distant stations.

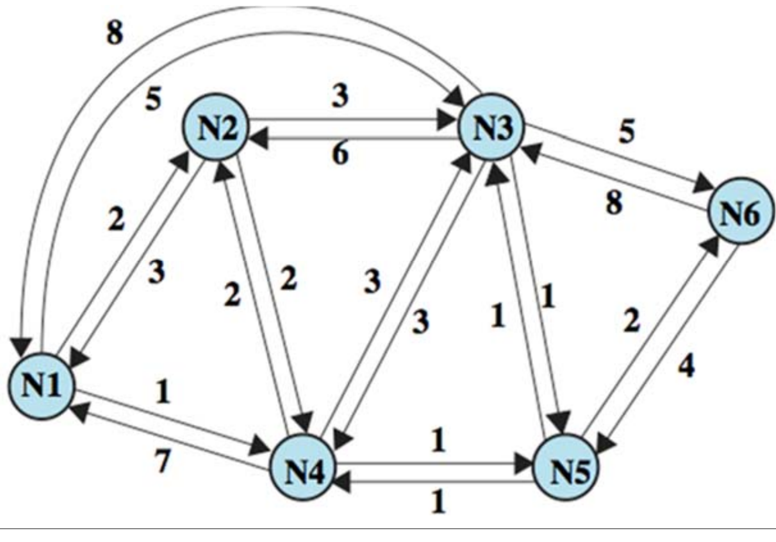
This policy may maximize average throughput but will appear unfair to the station that primarily needs to communicate with distant stations

- A cost is associated with each link, and, for any pair of attached stations, the route through the network that accumulates the least cost is sought.
- In either the minimum-hop or least-cost approach, the algorithm for determining the optimum route for any pair of stations is relatively straightforward, and the processing time would be about the same for either computation.
- Because the least-cost criterion is more flexible, this is more common than the minimum-hop criterion.
- Several least-cost routing algorithms are in common use.

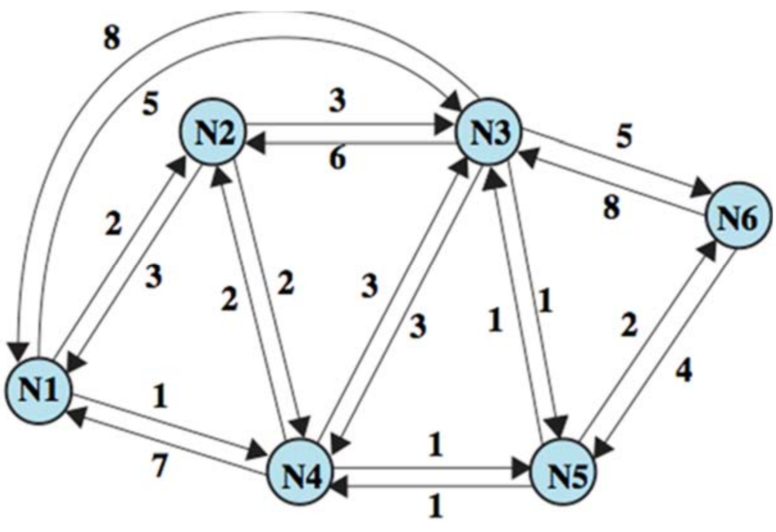
Link cost concept:



- Figure illustrates a network in which the two arrowed lines between a pair of nodes represent a link between these nodes, and the corresponding numbers represent the current link cost in each direction.
- The shortest path (fewest hops) from node 1 to node 6 is 1-3-6 (cost = 5 + 5 = 10),



- but the least-cost path is 1-4-5-6 (cost = 1 + 1 + 2 = 4).
- Costs are assigned to links to support one or more design objectives.



What is cost?

- cost could be inversely related to the data rate (i.e., the higher the data rate on a link, the lower the assigned cost of the link)
- the current queuing delay on the link.

- In the first case, the least-cost route should provide the highest throughput.
- In the second case, the least-cost route should minimize delay.

The Decision

- Routing decisions are made on the basis of some performance criterion.
- Two key characteristics of the decision are the
  - **time**
  - **Place**

Decision time?

- time is determined by whether the routing decision is made on a packet or virtual circuit basis.
- For datagram, a routing decision is made individually for each packet
- virtual circuit operation, a routing decision is made at the time the virtual circuit is established, so all subsequent packets using that virtual circuit follow the same route

Decision place

- *refers to which node or nodes in the* network are responsible for the routing decision.

1. distributed routing (most common is), in which each node has the responsibility of selecting an output link for routing packets as they arrive

   Dis/advantage: (more complex but is also more robust.).

2. centralized routing, the decision is made by some designated node, such as a network control center.

   Dis/advantage(the loss of the network control center may block operation of the network.)

3. source routing, decision made by the source station then communicated to the network. This allows the user to dictate a route through the network that meets criteria local to that user

Network information source and updating time

Now we can understand that, Routing decision based on

- knowledge of the topology of the network,
- traffic load,
- link cost.

- Information update timing, is a function of both the information source and the routing strategy
- the more information available, and the more frequently it is updated, the more likely the network is to make good routing decisions.
- On the other hand, the transmission of that information consumes network resources.

- For distributed routing:
  - the individual uses of only local information, such as the cost of each outgoing link.
  - Each node might also collect information from adjacent (directly connected) nodes, such as the amount of congestion experienced at that node.
  - A common algorithm is used to allow the node to gain information from all nodes on any potential route of interest.

- For central routing
  - the central node typically makes use of information obtained from all nodes.

Routing strategies

- Fixed routing
- Flooding
- Random
- Adaptive

1. Fixed routing (least cost)

- permanent route is configured for each source-destination pair of nodes in the network, using least-cost routing algorithms
- The routes are fixed, or at least only change when there is a change in the topology of the network.

Concerns

- The link costs used in designing routes cannot be based on any dynamic variable such as traffic.
- So route is based on the expected traffic or capacity.

- no difference between routing for datagrams and virtual circuits, all packets from a given source to a given destination follow the same route.

Advantage

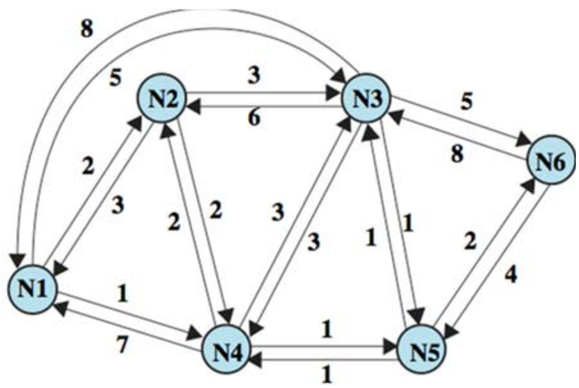
- simplicity,
- reliable network with a stable load.

disadvantage

- lack of flexibility.
- It does not react to network congestion or failures.

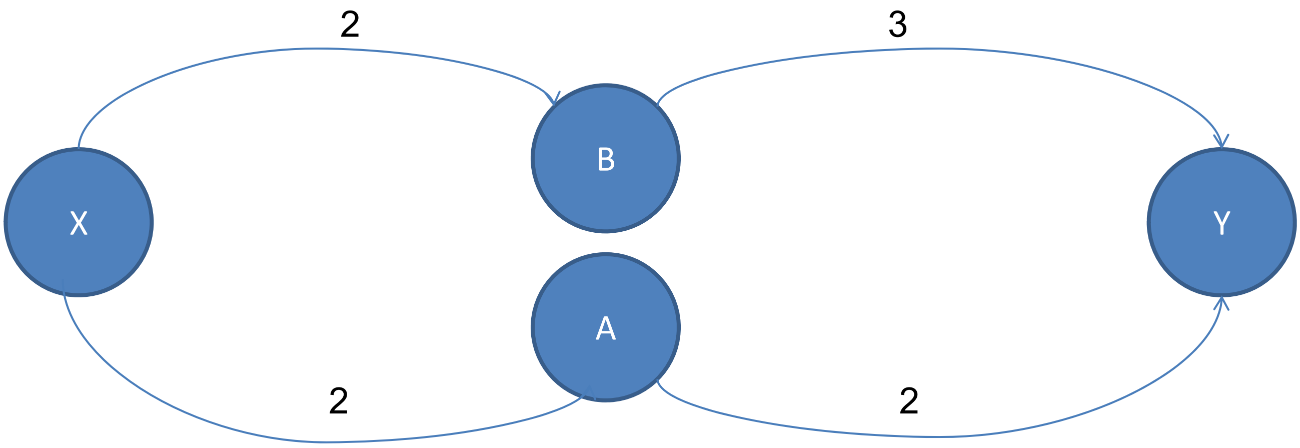
Build Fixed Routing Tables

- A central routing matrix is created, to be stored perhaps at a network control center.
- The matrix shows, for each source-destination pair of nodes, the next node on the route.
- Note that it is not necessary to store the complete route for each possible pair of nodes.
- Rather, it is sufficient to know, for each pair of nodes, the identity of the first node on the route.

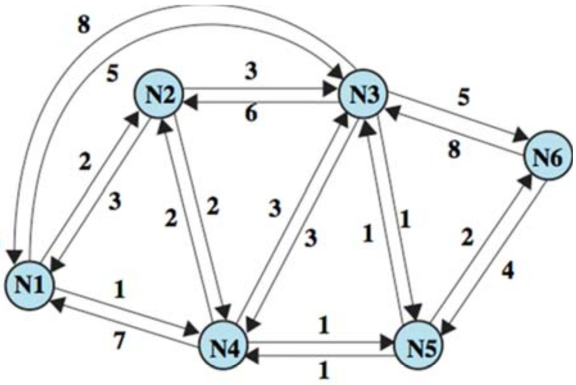


algorithm

- suppose that the least-cost route from *X to Y begins with the X-A link or A-B*
- *To decide the next hub for the route X-Y calculate the wait for the whole route, the next hub of the least cost route is selected*



- it is only necessary to know the identity of the next node, not the entire



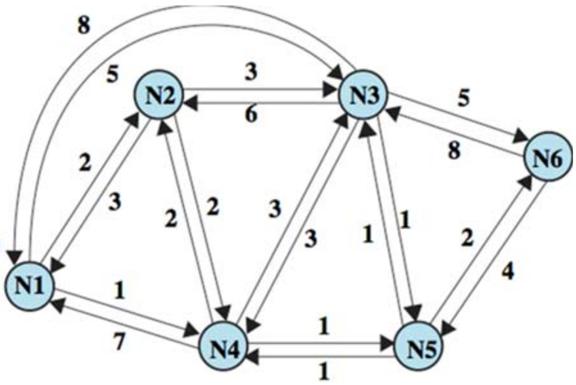
- In our example, the route from node 1 to node 6 begins by going through node 4.
- Again consulting the matrix, the route from node 4 to node 6 goes
- through node 5.
- Finally, the route from node 5 to node 6 is a direct link to node 6.
- Thus, the complete route from node 1 to node 6 is 1-4-5-6.
- From this overall matrix, routing tables can be developed and stored at each node.

Node 1 Directory

Destination	Next Node
2	2
3	4
4	4
5	4
6	4

Node 2 Directory

Destination	Next Node
1	1
3	3
4	4
5	4
6	4



- From the reasoning in the preceding paragraph, it follows that each node need only store a single column of the routing directory.
- The node's directory shows the next node to take for each destination.

Node 3 Directory

Destination	Next Node
1	5
2	5
4	5
5	5
6	5

Node 4 Directory

Destination	Next Node
1	2
2	2
3	5
5	5
6	5

Node 5 Directory

Destination	Next Node
1	4
2	4
3	3
4	4
6	6

Node 6 Directory

Destination	Next Node
1	5
2	5
3	5
4	5
5	5

CENTRAL ROUTING DIRECTORY

To Node \ From Node	1	2	3	4	5	6
1	—	1	5	2	4	5
2	2	—	5	2	4	5
3	4	3	—	5	3	5
4	4	4	5	—	4	5
5	4	4	5	5	—	5
6	4	4	5	5	6	—

Node 1 Directory

Destination	Next Node
2	2
3	4
4	4
5	4
6	4

Node 2 Directory

Destination	Next Node
1	1
3	3
4	4
5	4
6	4

Node 3 Directory

Destination	Next Node
1	5
2	5
4	5
5	5
6	5

Node 4 Directory

Destination	Next Node
1	2
2	2
3	5
5	5
6	5

Node 5 Directory

Destination	Next Node
1	4
2	4
3	3
4	4
6	6

Node 6 Directory

Destination	Next Node
1	5
2	5
3	5
4	5
5	5

2. **Flooding (number of hubs)**

- This technique requires no network information whatsoever and works as follows.
- A packet is sent by a source node to every one of its neighbors.
- At each node, an incoming packet is retransmitted on all outgoing links except for the link on which it arrived.
- Eventually, a number of copies of the packet will arrive at the destination.
- The packet must have some unique identifier (e.g., source node and sequence number, or virtual circuit number and sequence number) so that the destination knows to discard all but the first copy.

Problem:

retransmission of packets, the number of packets in circulation just from a single source packet grows without bound.

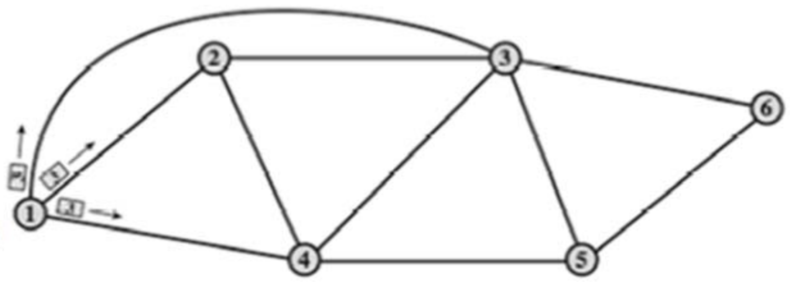
Solution

1. To prevent this each node remembers the identity of those packets it has already retransmitted.

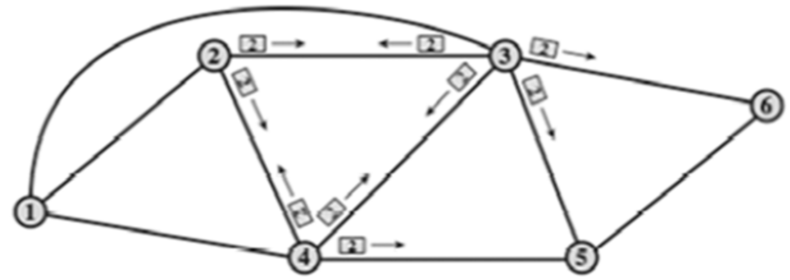
   When duplicate copies of the packet arrive, they are discarded.

2. Is to include a hop count field with each packet.

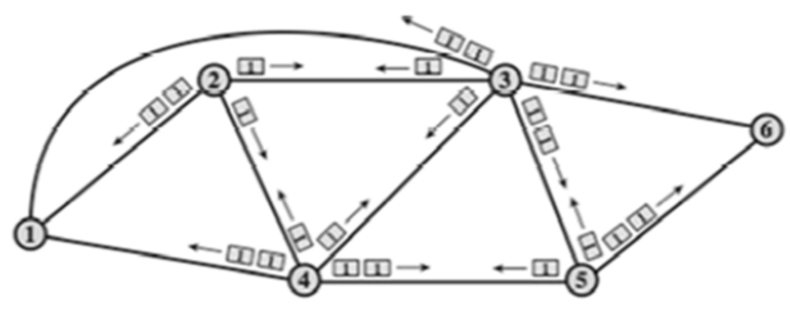
   The count can originally be set to some maximum value, such as the diameter, (length of the longest minimum-hop path through the network) of the network.



(a) First hop



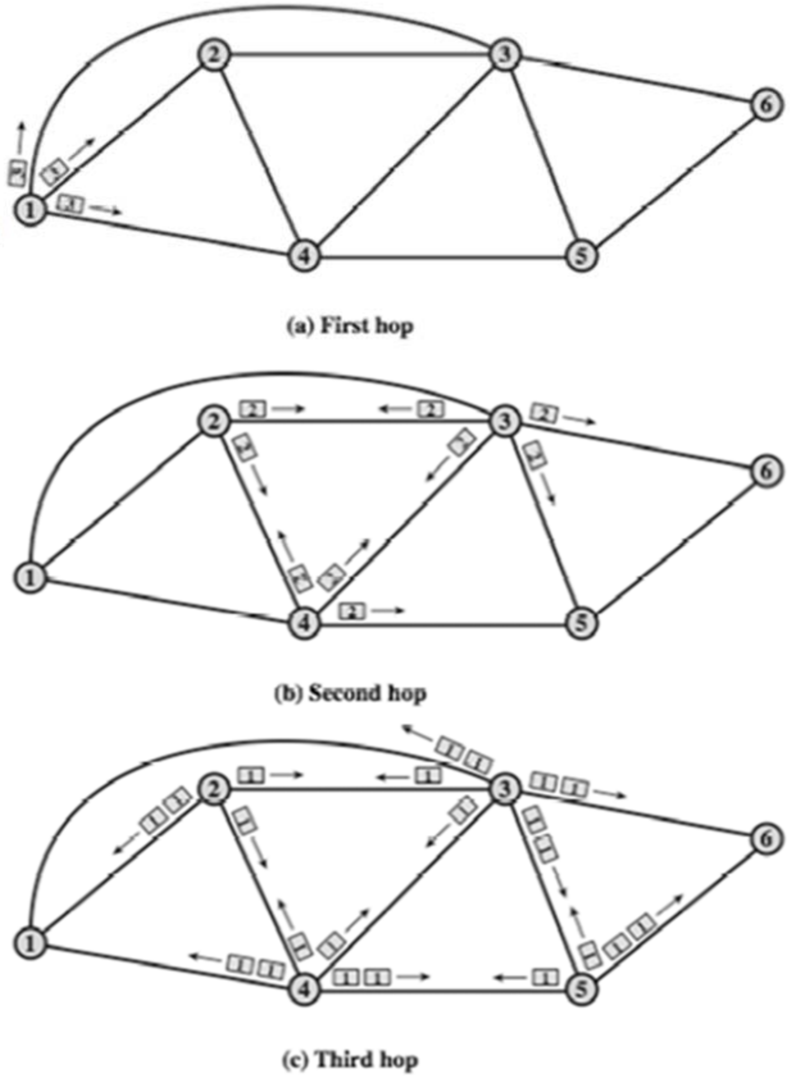
(b) Second hop



(c) Third hop

- The label on each packet in the figure indicates the current value of the hop count field in that packet.
- A packet is to be sent from node 1 to node 6 and is assigned a hop count of (3) longest minimum-hop path.
- On the first hop, three copies of the packet are created, and the hop count is decrement to 2.

- For the second hop of all these copies, a total of nine copies are created.
- One of these copies reaches node 6, which recognizes that it is the intended destination and does not retransmit.

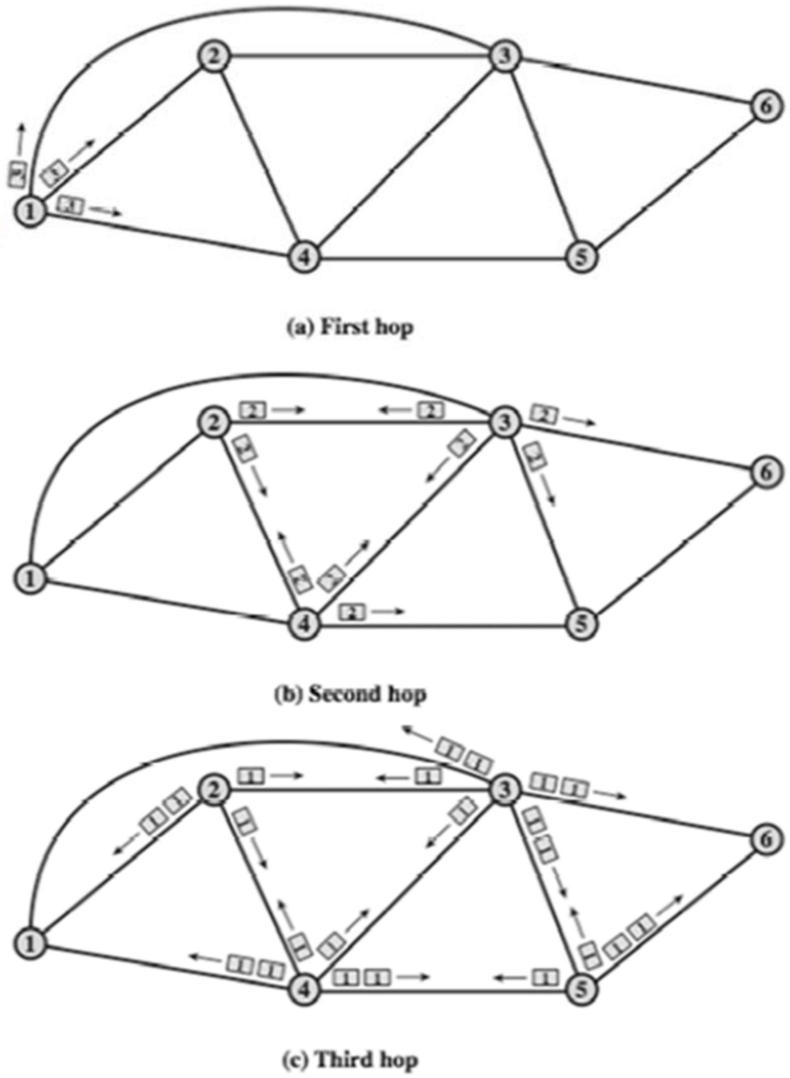


(a) First hop

(b) Second hop

(c) Third hop

- However, the other nodes generate a total of 22 new copies for their third and final hop.
- Each packet now has a hope count of 1.
- Note that if a node is not keeping track of packet identifier, it may generate multiple copies at this third stage.



(a) First hop

(b) Second hop

(c) Third hop

The flooding technique properties:

- All possible routes between source and destination are tried. Thus, no matter what link or node outages have occurred, a packet will always get through if at least one path between source and destination exists
- Because all routes are tried, at least one copy of the packet to arrive at the destination will have used a minimum-hop route.
- All nodes that are directly or indirectly connected to the source node are visited.

Flooding technique advantages & applications

highly robust and could be used to send emergency messages.

1. Example is a military network that is subject to extensive damage.
2. flooding might be used initially to set up the route for a virtual circuit.
3. flooding can be useful for the dissemination of important information to all nodes; used in some schemes to disseminate routing information.

Flooding technique disadvantages

- high traffic load that it generates, which is directly proportional to the connectivity of the network.

3. Random Routing

- Random routing has the simplicity and robustness of flooding with far less traffic load.
- With random routing, a node selects only one outgoing path for retransmission of an incoming packet.
- The outgoing link is chosen at random, excluding the link on which the packet arrived.

How to choose

- assign a probability to each outgoing link and to select the link based on that probability.
- The probability could be based on data rate, or on fixed link costs.
- If all links are equally likely to be chosen, then a node may simply utilize outgoing links in a round-robin fashion.
- Like flooding, random routing requires the use of no network information.
- Because the route taken is random, the actual route will typically not be the least-cost route nor the minimum-hop route.

Routing protocols (cont,..)

4. Adaptive routing

- Most packet-switching networks, use some sort of adaptive routing technique.

Definition

- The routing decisions that are made change as conditions on the network change.
- The principal conditions that influence routing decisions are:

1. **Failure:** When a node or link fails, it can no longer be used as part of a route.
2. **Congestion:** When a particular portion of the network is heavily congested, it is desirable to route packets around rather than through the area of congestion.

Key requirements for adaptive routing:

- For adaptive routing to be possible, information about the state of the network must be exchanged among the nodes.

  (like fixed, unlike flooding and random)

Key disadvantages

There are several drawbacks associated with the use of adaptive routing, compared to fixed routing:

1. The routing decision is more complex; therefore, the processing burden on network nodes increases.
2. In most cases, adaptive strategies depend on status information that is collected at one place but used at another.
   - There is a tradeoff here between the quality of the information and the amount of overhead.
   - The more information that is exchanged, and the more frequently it is exchanged, the better will be the routing decisions that each node makes.

– On the other hand, this information is itself a load on the constituent networks, causing a performance degradation.

3. An adaptive strategy may react too quickly, causing congestion-producing oscillation, or too slowly, being irrelevant.

Conclusions

- These benefits may or may not be realized, depending on the
- soundness of the design and the nature of the load.
- By and large, adaptive routing is an extraordinarily complex task to perform properly.
- Most major packet-switching networks, such as ARPANET (internet godfather) and its successors, and many commercial networks, have endured at least one major overhaul of their routing strategy.

Key advantages of adaptive routing

- An adaptive routing strategy can improve performance, as seen by the network user.
- An adaptive routing strategy can aid in congestion control as an adaptive routing strategy tends to balance loads, it can delay the onset of severe congestion.

Classification of Adaptive Routing Strategies

basis of information source:

- Local (Isolated)
- adjacent nodes
- all nodes

1. Local (isolated) (rarely used)

- a node routes each packet to the outgoing link with the shortest queue length, *Q (which will* balance the load on outgoing links).
- Some outgoing links may not be headed in the correct general direction.
- This can be improved by selecting preferred direction, as with random routing.
- So each would have a bias B_i, *for each destination i, such that lower values of* B_i *indicate more preferred* directions.
- For each incoming packet headed for node *i, the node would choose* the outgoing link that minimizes $Q + B_i$.

2,3 . Adjacent and all nodes (commonly used)

- Each node knows its queue delays and its outages that it experiences.
- So each node tell (adjacent or all other nodes) about its local information.
- Such adaptive strategies can be either
  - Distributed
  - centralized.

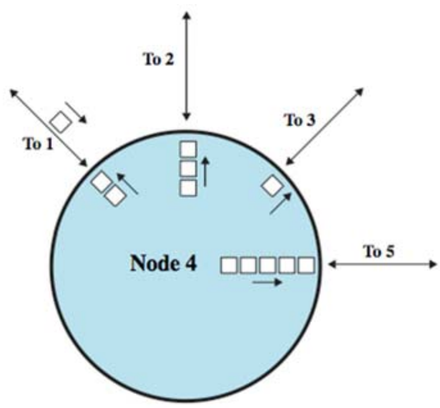
- **In the distributed case,**
  - each node exchanges delay information with other nodes.
  - Based on incoming information, a node tries to estimate the delay situation throughout the network, and applies a least-cost routing algorithm.
- **In the centralized case,**
  - each node reports its link delay status to a central node, which designs routes based on this incoming information and sends the routing information back to the nodes.

Isolated adaptive routing example:

- Node 4 has links to four other nodes.
- A fair number of packets have been arriving and a backlog has built up, with a queue of packets waiting for each of the outgoing links.
- A packet arrives from node 1 destined for node 6.

Node 4's Bias Table for Destination 6

Next Node	Bias
1	9
2	6
3	3
5	0



To which outgoing link should the packet be routed?

- Based on current queue lengths and the values of bias (B_6) *for each outgoing link, the* minimum value of $Q + B_6$ *is 4, on the link to node 3.*
- *Thus, node 4 routes the* packet through node 3.

Node 4's Bias Table for Destination 6

Next Node	Bias
1	9
2	6
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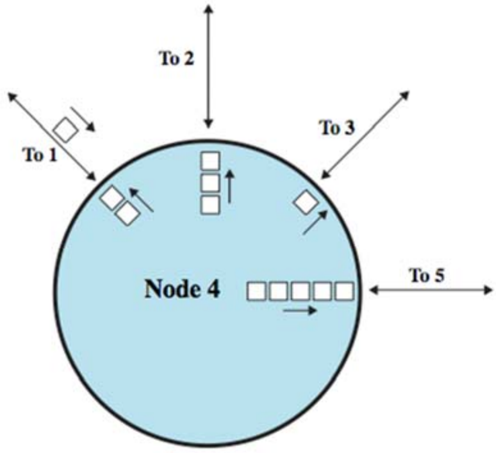
5	0



ARPANET Routing Strategies

- ARPANETis a packet-switching network that was the foundation of the present-day Internet.
- Several routing strategies were initially developed for ARPANET.

1. 1st generation, 1969
2. 2nd generation,1979
3. 3rd generation, 1987

ARPANET Routing Strategies 1st Generation, 1969

- each node maintains two vectors:
  - *Di = delay vector for node i, and*
  - *Si = successor node vector for node i.*
- *Periodically (every 128 ms), each node exchanges its delay vector with all of its* neighbors, which update both of their vectors using that info.
- The estimated link delay is simply the queue length for that link.

Strength point

- While building a new routing table, the node will tend to favor outgoing links with shorter queues.
- This tends to balance the load on outgoing links.

Weak point

- queue lengths vary rapidly with time, the distributed perception of the shortest route could change while a packet is en route.
- This could lead to a thrashing situation in which a packet continues to seek out areas of low congestion rather than aiming at the destination.

ARPANET Routing Strategies 2nd Generation, 1979

- It uses delay as the performance criterion. Rather than using queue length as a surrogate for delay.

Delay measurement

- At a node (Tx), A departure time is recorded when the packet is transmitted.
- At another node (Rx), each incoming packet is time stamped with an arrival time.
- If a positive acknowledgment is returned containing the arrival time,
- At the Tx node the delay for that packet is recorded as the departure time minus the arrival time plus transmission time and propagation delay.

Distributing the link delay information

- Every 10 seconds, the node computes the average delay on each outgoing link.
- If there are any significant changes in delay, the information is sent to all other nodes using flooding.
- Each node maintains an estimate of delay on every outgoing network link.
- When new information arrives, each node recomputes its routing table using Dijkstra's algorithm.

Performance of new algorithm

- Experience with this new strategy indicated that it was more responsive and stable than the old one.
- The overhead induced by flooding was moderate because each node does this at most once every 10 seconds.

Back draws of new algorithm

- as the load on the network grew, a shortcoming in the new strategy began to appear,

Why?

- due to the assumption that the measured packet delay on a link is a good predictor of the link delay encountered after all nodes reroute their traffic based on this reported delay.

Why?

After calculating delay of all outgoing link from a node (n),

If a prefered link for certain destination is L1 and node found L1>L2 (which is logic as queue will increase on L1)

Node notice a change in delay, so it rebuild a new routing table regarding new delay so and L2 become prefered link for the that destination.

Now all packet will go through L2 and queue at L2 will increase, so after a while L2 delay will be greater that L1.

Node will rebuild a new routing table, and preferred link will be L1 again and so on.

Solution

- A correlation between the reported values and those actually experienced after rerouting.
- This correlation tends to be rather high under light and moderate traffic loads.
- However, under heavy loads, there is little correlation. Therefore, immediately after all nodes have made routing updates, the routing tables are obsolete!

ARPANET Routing Strategies 3rd Generation (1987)

Discovering the problem

- The ARPANET designers concluded that the problem was that every node was trying to obtain the best route for all destinations, and that these efforts conflicted.

Suggesting the solution

- It was concluded that under heavy loads, the goal of routing should be to give the average route a good path instead of attempting to give all routes the best path.
- The designers decided that it was unnecessary to change the
- overall routing algorithm.
- Rather, it was sufficient to change the function that calculates link costs, and this was revised in 1987. The

The algorithm

1. The calculation begins with measuring the average delay over the last 10 seconds.

2. Using a simple single-server queuing model, the measured delay is transformed into an estimate of link utilization.

3. Result is smoothed by averaging it with previous estimate of utilization.

4. The link cost is then set as a function of average utilization that is designed to provide a reasonable estimate of cost while avoiding oscillation.

Issues regarding the new algorithms

- The revised cost function is keyed to utilization rather than delay.
- The function acts similar to a delay-based metric under light loads and to a capacity based metric under heavy loads.
- The cost value is kept at the minimum value until a given level of utilization is reached.
- This feature has the effect of reducing routing overhead at low traffic levels.

- Above a certain level of utilization, the cost level is allowed to rise to a maximum value that is equal to three times the minimum value.
- The effect of this maximum value is to dictate that traffic should not be routed around a heavily utilized line by more than two additional hops.

Thanks,…