Data Communications
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Lecture -21
Routing-II

Hello and welcome to the second lecture on routing on packet switched networks. In the first lecture we have discussed the basic issues related to routing in packet switched networks particularly why routing is needed, what are the parameters to be considered when you design routing algorithms and various constants. And we have discussed few important routing techniques such as fixed routing and flooding. So in this lecture we shall continue our discussion on routing techniques and here is the outline of today's lecture.

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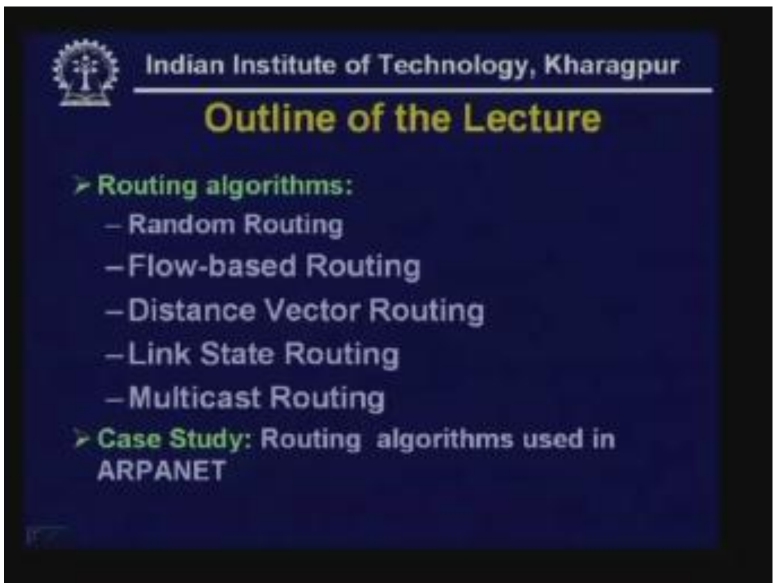

So we shall start with random routing and then we shall consider flow-based routing which is again one kind of fixed or static routing technique on the other hand,, Distance Vector routing and link state routing these two belong to the category of adaptive routing. We shall also discuss about multicast routing. Finally we shall consider the routing algorithms used in Arpanet the case study. Arpanet as you know is the foundation of internet technology. Various approaches, tools and techniques were developed in Arpanet which is nothing but Advance Research Program Network. Here various techniques were developed and we shall discuss and see how the routing algorithms evolved as a part of Arpanet. Here is what the students will learn.

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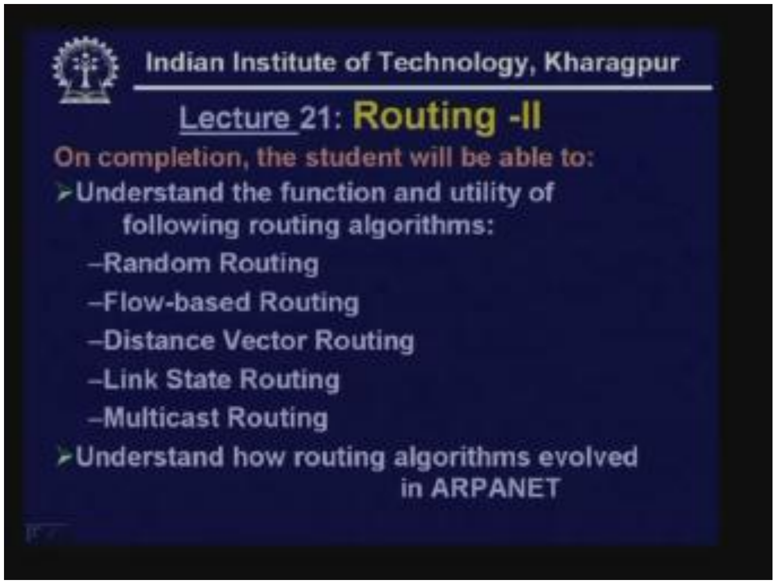

On completion the student will be able to understand the function and utility of the following routing algorithms: random routing, progress routing, Distance Vector routing, link state routing and multicast routing and also they will understand how routing algorithms evolved in Arpanet. Let us start with the various routing techniques. As I mentioned we have already discussed fixed routing and flooding and in this lecture we shall consider the other approaches and as I mentioned a large number of routing strategies have evolved over the years and here is the least of the important ones so we shall consider these techniques in this lecture.

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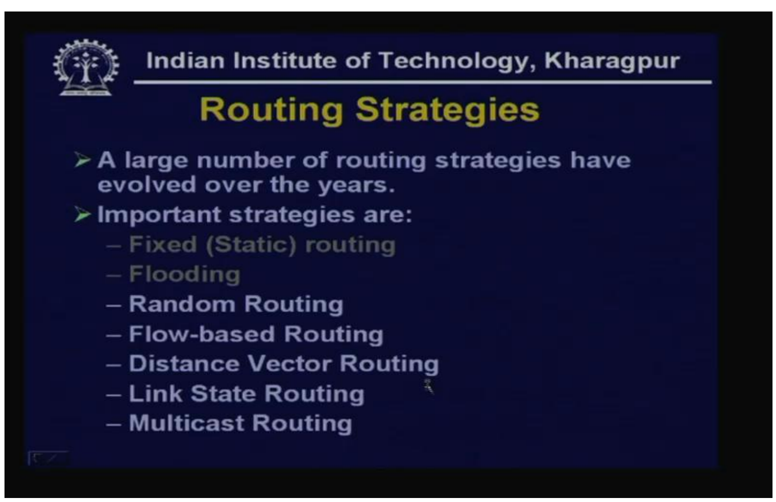

Let us start with random routing. This can be considered as a special case of flooding. we have already discussed flooding and we have seen in flooding it leads to too many packets and also it leads to too much load on the network so that can be somewhat reduced with the help of this random routing and it has the simplicity and robustness of flooding with far less traffic. So it gives you some benefits of flooding and at the same time it reduces or overcomes some of the limitations of flooding that means it reduces the traffic load which is the main drawback of flooding.

What is being done is a node selects only one outgoing path for retransmission of an incoming packet. Suppose we consider a particular node in a subnet and suppose this is the link through which a packet has been received and these are the various outgoing links (Refer Slide Time: 4:56) so as we have seen in case of flooding if a packet is received here it is transmitted or forwarded on all the links except through which it has been received. But in random routing that is not done. The outgoing link is chosen at random excluding the link on which the packet has arrived that means it is not sent through this path but not only that it sends through one of the three paths it may be at random.

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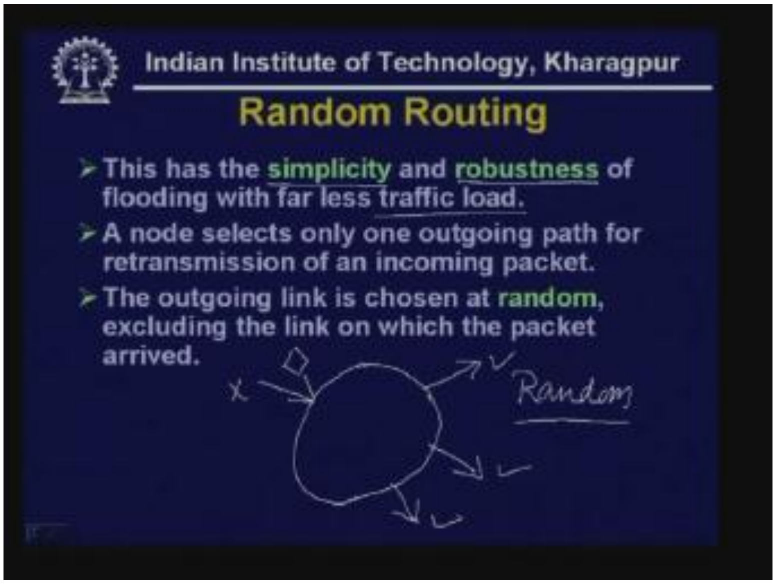

Now you may ask how you do it. If you do it at random there is no need for any other information of the present state of the network whether how many packets are in the queue or what is the bandwidth of the link and so on. Another possibility is that you can do it in a round Robin fashion. that means whenever there is no other criteria you may choose one of the links next time you may choose another link and next time you again choose another link so in this way you send through all the paths one after the other so you may call it round robin technique.

In this case it will distribute the load evenly on different links but unfortunately this has a limitation. The limitation is that some of the packets may get forwarded in the direction of the source rather than the direction of the destination that can be overcome by using some approach or another refinement is to assign probability to each outgoing link and to select the link based on probability. That probability can be computed based on may be data rate. Let us consider it now.

Suppose this is the link through which packet is come and these are the three outgoing links. Now let us assume the rate of transmission on these links are R_1 R_2 and R_3 then probability P_i of sending through a particular link can be computed in this way P_i is equal to R_i that is the rate of transmission through a particular link by summation of all these R_is.

That means in this particular case (Refer Slide Time: 7:35) here it will be R_1 plus R_2 plus R_3 that will be in the denominator and in the numerator it will be one of the links. Therefore based on these the probability can be calculated and the link having the highest probabilities is used for transmission. That means what is being done is the packet is forwarded in a particular direction and for that the probability is calculated based on the bandwidth of that link. So the higher bandwidth is being referred for transmission so it can be done in this way also.

The actual route will typically not be the least-cost route. So whenever you do it in this manner you cannot guarantee that the route chosen is least-cost route because we are not considering the cost of the different routes in a systematic manner. As a consequence the transmission of packet will not go to the least-cost path and as a consequence the load on the network will be higher than the optimum traffic load.

Therefore we find that this random routing does not use any other information, it can be purely random or it can be round robin or if some information is used that can be the data rate of different links. And this has the advantage that the traffic and the network is significantly lower than the flooding. However, it has the robustness because it is sending through a particular path. That means ultimately the packet will be delivered to the destination like flooding so it has the robustness and simplicity of flooding but with much reduced traffic load. So this is random routing.

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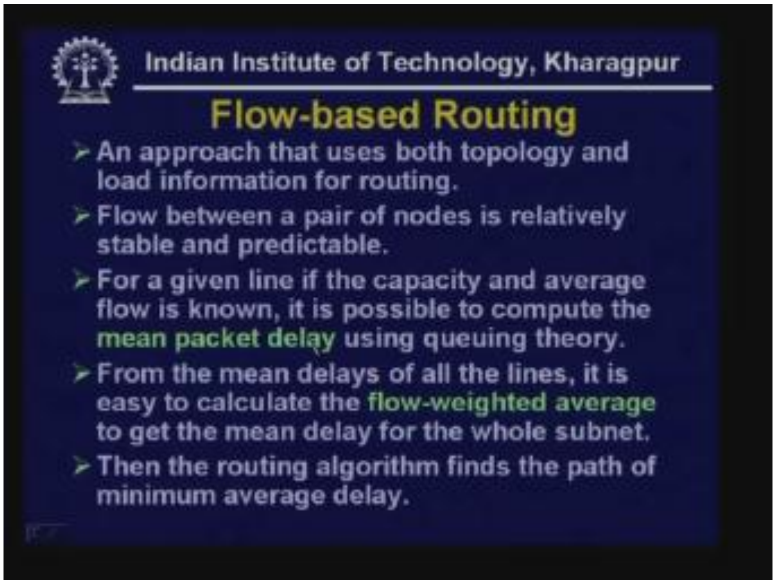

Then we have another important routing algorithm known as flow-based routing. So far in fixed routing we have seen that only the topology of the network has been taken into consideration. We have seen that the nodes are connected to different links and for each of these links either the queue length or the delay or the transmission time the actual data rate these are being used but not the information about the load of the flow.

Now what can be done is in addition to topology information about the load can be used for routing and a concept of flow is used here. The flow between a pair of nodes is relatively stable and predictable. That means if we know the traffic through a particular direction and the data rate of a particular link then very easily the flow between pair of nodes can be calculated.

So, for a given capacity that means the data rate of a particular link average flow is known, it is possible to compute the mean packet delay using queuing theory. Thus queuing theory can be used to compute the mean packet delay for each of the links and from the mean delays of all the lines it is easy to calculate flow-weighted average to get the mean delay for the whole subnet. So once you get the mean delay of the whole subnet that can be used for finding out the least-cost path by using Dijkstra's algorithm.

Therefore using that again the routing table is calculated and based on that the minimum average delay path is chosen so again it can be considered as a fixed or static routing. However, here we are taking into consideration not only the information about the topology but load information and it is based on flow. So this is another example of fixed routing that we have discussed here.

Now we have seen that the static or fixed routing techniques have a serious limitation particularly when the network is not stable. There are two principle conditions that affect routing decisions. One is failure. So when a particular node fails obviously you cannot pass a packet through that and obviously you have to reroute the traffic in some other direction. so when a node or trunk fails that means not only the node but a link or trunk may fail so it can no longer be used as a part of the route. So in this condition obviously the fixed routing will not work because fixed routing will always use the routing table which does not take into consideration the failure of a node or a link.

Another possibility is congestion. We shall discuss about congestion in next lecture in detail and we shall we see that when a particular portion of the network become heavily congested it is desirable to route packets around the area of congestion. As in a normal traffic scenario where the vehicles are controlled whenever there is a traffic jam in a particular area usually the cars or other vehicles are diverted through some other route. So the same technique has to be used here. It is necessary to reroute the traffic such that it does not go through the congested area but around the congested area. That is adaptive routing. So, the adaptive routing will keep on modifying the routing table or whatever it may be so that the dynamic condition because of failure and congestion is taken care of. And the classification of these adaptive algorithms can be done based on the information source.

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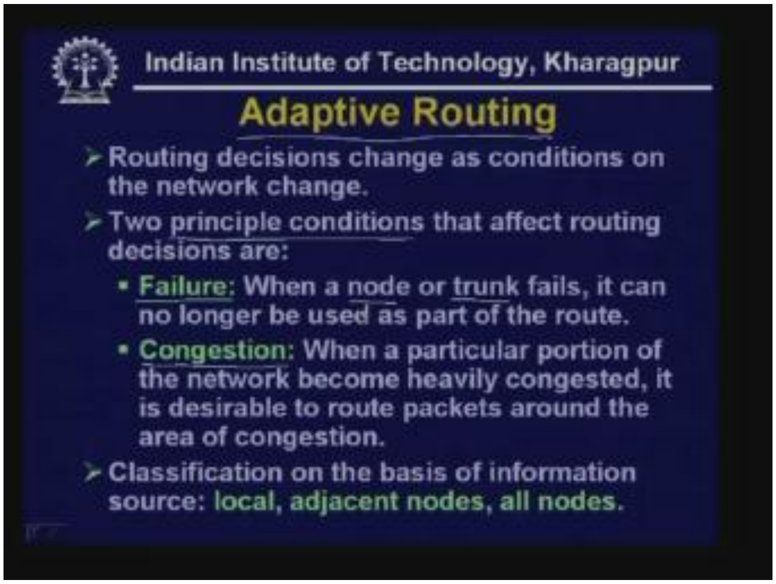

There are three alternatives about the information source. Information source can be purely local. In such a case what is being done is information is gathered from that node itself. That means it may be the queue length on different links of a particular node so in that case it is purely local. That means it shows how many packets have been accumulated in each of these links. So this is purely a local information that can be used for routing.

Another possibility is that we can use adjacent nodes. that means each node can gather information from its neighbors to which a particular node is directly connected so that can be used for routing in a such case information gathering is taking place from adjacent nodes.

Another alternative is the information can be gathered from all nodes. So in a packet switch network then may be many nodes so each node will gather information from all other nodes. hence in such a case it is more global obviously whenever it is more global more information has to be gathered so it will take more time and it will put more on the network because whenever we gather information obviously exchange of packets will take place and that will put some load and also the node has to do computation for using this information gathered from all the nodes for the purpose of routing. so classification can be done based on these three approaches.

Then for adaptive routing to be possible network state information must be exchanged among the nodes. Now you may be asking what kind of metric can be used for the purpose of routing. One simple approach is to use number of hops. So, for a particular source to destination the information about the number of hops the number of nodes to be used for relaying or retransmitting or forwarding the packets can be used as a metric. This is possibly the simplest metric that can be used.

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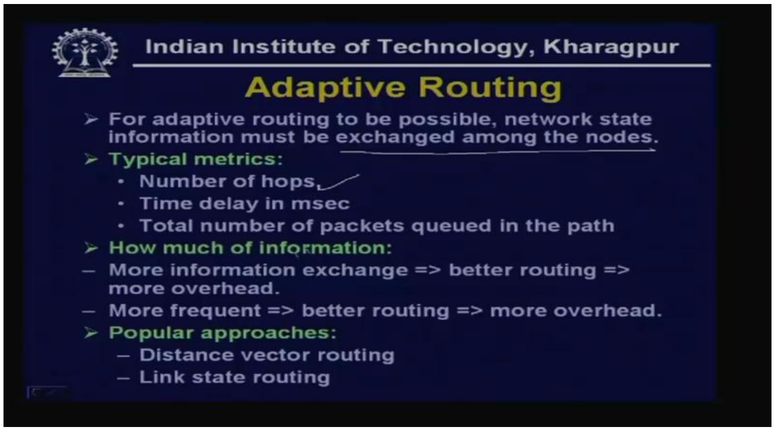

However, this particular metric is not commonly used. Second metric that can be used is the time delay in millisecond. So this time delay in millisecond can be used. However, how do you get information about the time delay? One representative of this time delay information is the queue length. One can use the queue length for each outgoing link towards a particular node so this can be used. Another approach is that the delay can be actually measured and based on that the time delay can be used and the total number of packets queued in the path. So here it can be more global approach. Here what we are doing is the packet queued along the path from source to destination is used as a metric for finding out the route.

Here we find there is a trade off. More information exchange you do that means if the information is more global if you gather more information there is a possibility that routing strategy will be better. On the other hand, if it is based on local information or no information as you have done in case of flooding and routing then the routing strategy may not be very good. So what is happening is whenever more information exchange is used for better routing that increases overhead. So we find that it is essentially a trade off between better routing and more overhead. That means if you want lesser overhead then we cannot get better routing. On the other hand, if you want better routing then the overhead on the network increases.

Another important parameter is frequency. That means if it is more frequent you can perform better routing but it will be more overhead. That means if the information gathering takes place more frequently then obviously the routing will be better. On the other hand, if the information gathering takes place after a large interval then the routing that is being done based on the information may not be very relevant and by the time that information is used for routing the network parameter may change. So the more frequent the better but it increases the overhead. Therefore these are the trade off that will be encountered whenever you design adaptive routing algorithms. So as a consequence it will be quite complex.

There are very two popular approaches for adaptive routing. One is known as Distance Vector routing and another is link state routing. We shall discuss about them in detail in this lecture but before that let us take a very simple example of adaptive routing technique. It is essentially local approach that is why it is known as isolated adaptive routing. In this case a node routed an incoming packet to the outgoing link with the shortest queue length Q. So based on the queue length in different paths the routing is done. Thus the basic idea is that it will do the balancing of the load on outgoing links so the chosen outgoing link may not be heading in the right direction. Unfortunately what can happen is whenever it is based queue length of different links then there is a possibility that a packet will be headed towards the source rather than the destination.

How do you take that into consideration? to take direction into account each link emanating from the node has a bias so the basic approach is modified and bias is used for each destination I. for each arriving packet heading for a node I the node would choose the outgoing link that minimizes Q plus Bi that is the queue length the bias these two are added together which minimizes Q and Bi which is used for linking.

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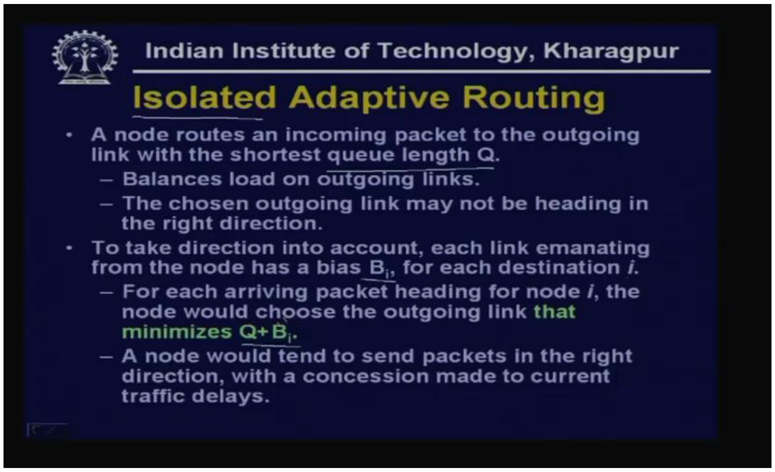

And whenever you do that a node would tend to send packets in the right direction with a concession made for the current traffic delay. That means this Q factor takes into account the current traffic delay. On the other hand, this Bi that is your bias will try to send in the right direction. Let us take an example for that.

Suppose here we have considered a node in this network with destination at this 5 that means a packet is going from node 2 which is here (Refer Slide time: 22:08) towards 5. So from 2 it is going to 5 and this node 4 in between is shown here.

As you can see the node 4 has got four links and queue length on different links towards node 2, node 4, node 6, node 5 and 3 are shown here. So queue length towards 2 is 2, towards 6 is 1, towards 5 is 4 and towards 3 is 3. On the other hand, there is a bias table.

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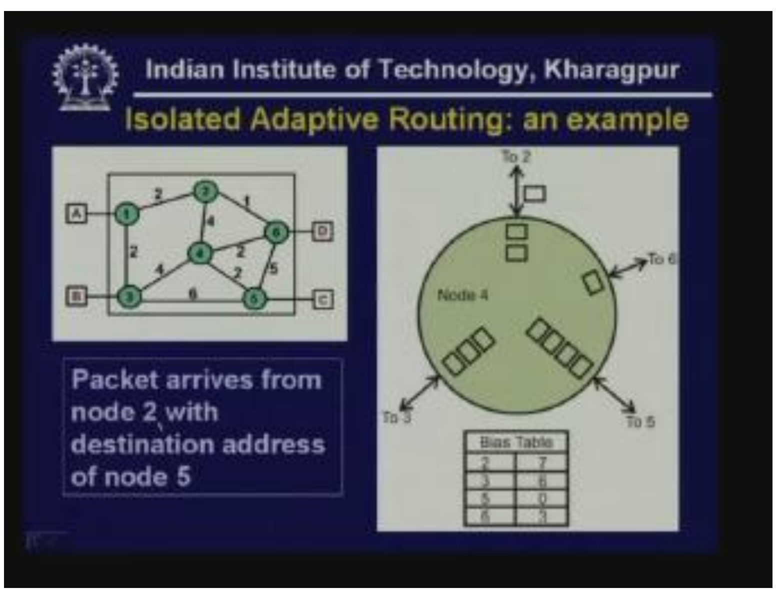

As you can see bias towards 2 is 7 because it is going in the direction of the source that is why here the bias is more. On the other hand, towards 3 if it goes the bias is 6 because again it is going away and on the other hand, if it is going in this direction (Refer Slide Time: 23:09) bias is 0 and whenever it is going in this direction again it is going little off so bias is 3. Therefore if you add 2 plus 7 is equal to 9, 1 plus 6 is equal to 7, 0 plus 4 is equal to 4 and 3 plus 3 is equal to 5 then it is directly delivered to 5 because although four packets are there but because of zero bias it is directly forwarded to 5. So we find that if only the queue length was used then the packet would have been forwarded towards 6. That means in this direction again it would come in this way, so it would have taken a longer path but that is being avoided because with the help of the bias.

So because of zero bias the node 4 is forwarded directly to 5 although the queue length is 4 here. So we find that by using local information and also using suitable bias it has been possible to do the routing in an effective manner in this isolated adaptive routing.

Now as I mentioned one of the most popular adaptive routing technique is Distance Vector routing.

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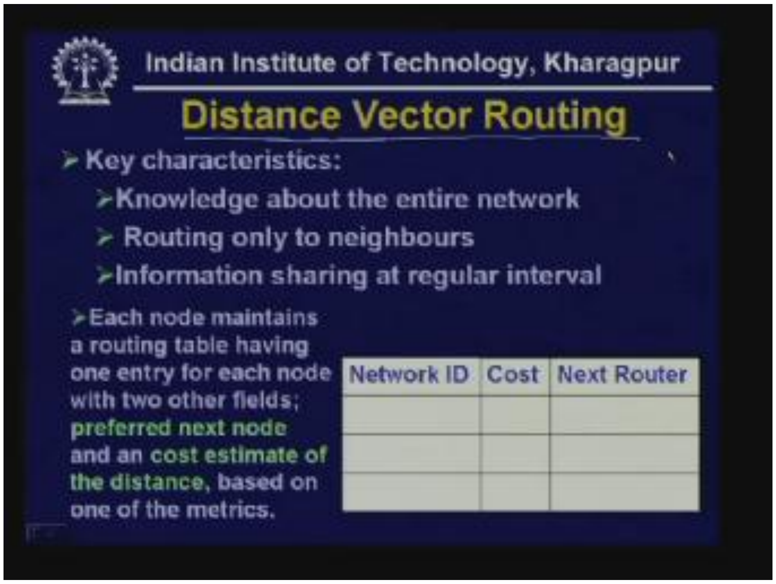

These are the key characteristics of Distance Vector routing. In Distance Vector routing knowledge about the entire network is gathered and routing only to the neighbors. However, the routing is done only to the neighbors and that is why here we find that a table is maintained based on the information sharing at regular intervals. These are the three basic features of this.

First of all knowledge about the entire network is gathered and routing is done only to the neighbors and information sharing is performed at regular interval. Based on that each node maintains a routing table having only 1 and 3 for each node with two other fields so these essentially adjusts the destination node. And here (Refer Slide Time: 25:46) the cost is computed based on the information shared at regular interval. That information that is being gathered is stored here. And with the help of this preferred next node this is the next hop node that is being mentioned. So, from this table each node gets the information about the cost and also the next hop node. And based on this cost information the routing can be used based on the Bellman-Ford algorithm or some other least-cost path algorithm. Hence in this way the node maintains a routing table and the minimum cost route is used for routing purpose. This is Distance Vector routing. Then comes the link state routing

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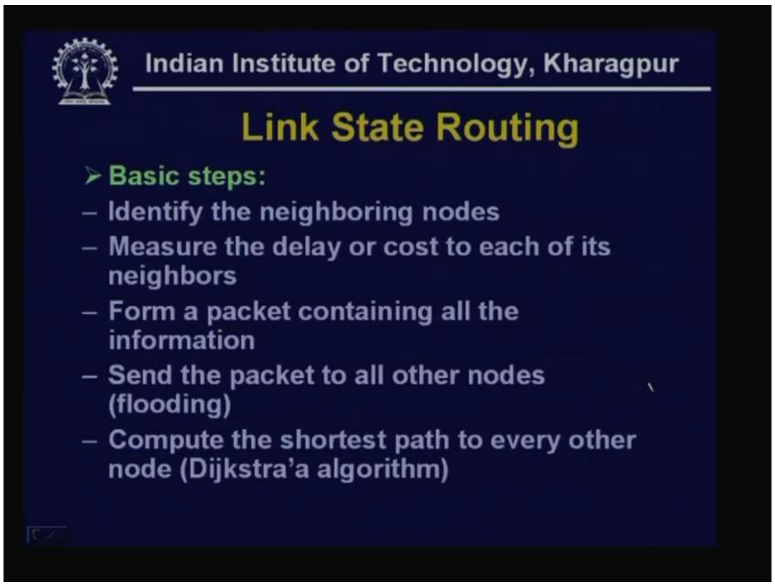

In link state routing the basic steps are; identify the neighboring nodes, measure the delay or cost to each of its neighbors and so on. Therefore here as you can see in the previous case the knowledge about the entire network was gathered in Distance Vector routing. So the distance and cost vectors are being maintained here. on the other hand, here only the information about the delay or cost to each of the neighbors is computed and then form a packet containing all the information and send the packet to all other nodes. So, in the previous case information was sent only to the neighbors. On the other hand, here the information is being sent to all the nodes and obviously it is being done by flooding. Here although information gathering is taking only from neighboring nodes but the distribution of information is taking place to all other nodes so compute the shortest path to every other node by using Dijkstra's algorithm.

In this case the information is gradually gathered based on the information received from all other nodes and then the routing is done. Thus the basic idea is as you can see it uses knowledge about the neighborhood and then routing to all by using flooding. It uses flooding to send information to all the nodes and information sharing is performed at regular interval just like your Distance Vector routing.

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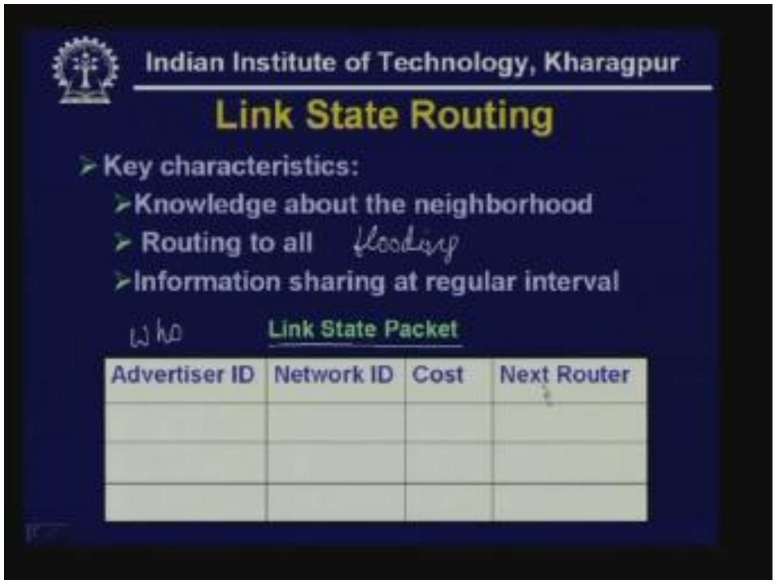

This link state packet is sent to all the other nodes, this is the advertiser ID (Refer Slide Time: 28:55) that is the person or thing who is sending the packet. As we have seen although information gathering is taking place from the neighborhood it is being sent to all other nodes. As a consequence the nodes should know who is doing the advertisement or who is passing on the information. So this advertiser ID tells each node from where the information is coming and the network ID is essentially the destination node's address and cost for transmission is given here for that destination and the next hop node ID number is given here. So all this information that appear in these four columns is used known as link state packet.

Link state packet is broadcasted with the help of flooding to all the nodes and all the nodes will gradually gather information. initially it may be sparse but as time passes and more and more information is received from different nodes then each and every node may make some kind of database and they will use that database to find out the shortest path to every other node and then using the Dijkstra's algorithm each link is obtained and then the shortest path is found to every other node which is then used for routing purpose. So we find that this link state routing is quite powerful and here let us make a comparison between the link state versus Distance Vector routing. so link state algorithm converge more quickly and are somewhat less prone to routing loops than Distance Vector routing.

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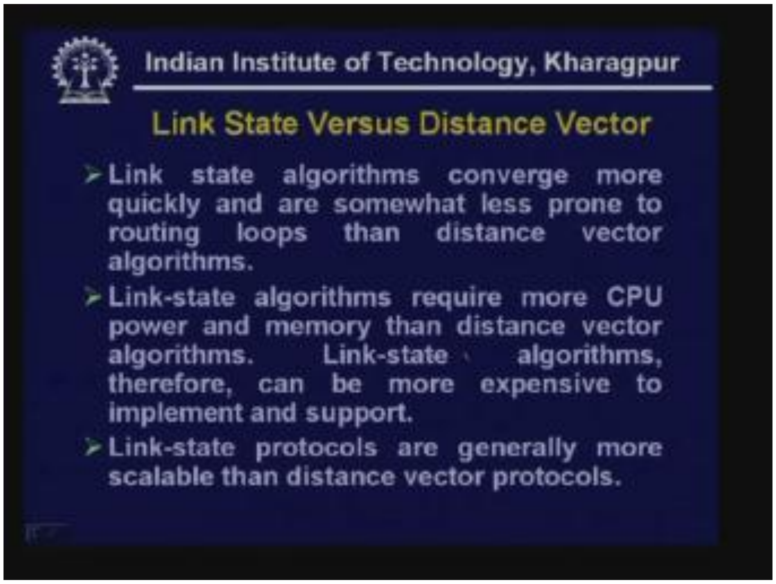

It has been observed that the link state algorithms which I have discussed just now converge more quickly and are somewhat less prone to routing loops than the Distance Vector routing. However, link state algorithms require more CPU power and memory than Distance Vector algorithms. Link state algorithms therefore can be more expensive to implement and support.

As we have seen in case of link state routing the nodes are gradually gathering information for making a database and the database will require lot of memory then they have to do the computation on the database. Therefore each and every node that is developed will use the Dijkstra's algorithm to get the least-cost path to each of the destination node. And as a consequence it will be little expensive to implement and support it however link state protocols are generally used. Particularly they are more scalable than Distance Vector routing. So link state routing has been found to be more scalable compared to Distance Vector routing and that is why the link state routing are becoming more and more popular.

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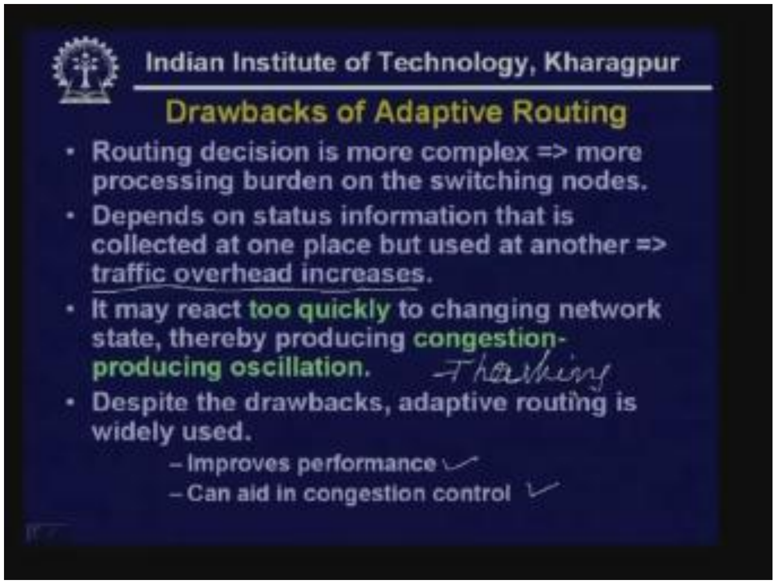

So far we have discussed about three adaptive algorithms. First one was isolated adaptive routing which uses local information. On the other hand, Distance Vector routing uses information from the neighbors and Distance Vector routing gathers information from all the nodes. And we find that the routing decisions are more complex and has more processing burden on the switching nodes. That means compared to fixed routing or flooding or random routing we find that adaptive routing is more complex and obviously they will put more and more processing burden on the nodes. Therefore it depends on status information that is collected at one place but used at another. So what is happening is the information about the network status that is queue length, delay or whatever it may be is being gathered at different nodes in network, however, the decision has to be taken not in the nodes but in the stations or computers. So as a result they have to be transmitted to them and that increases the traffic overhead significantly.

If it reacts too quickly to changing network state it may produce congestion producing oscillations. That means if the adaptive algorithms reacts too quickly then it may lead to congestion producing oscillation somewhat like this. Suppose there is a traffic jam in a particular part of the city and very quickly all the traffic is diverted to another part of the city so that part of the city where the traffic is diverted to will have a major traffic jam and in this way the traffic will hop between two areas instead of going to the destination so somewhat similar kind of a situation can arise here known as thrashing situation.

This thrashing situation may arise unless it is carefully implemented but this has to be avoided. However, in spite of these drawbacks adaptive routing is widely used because of improved performance and can aid in congestion controls. Although it is complex, although it may lead to some congestion producing oscillation adaptive routing is still referred because it improves the performance of routing and also it can aid in congestion control.

Congestion is a very important aspect of packet switched network and congestion has to be controlled at any cost and this adaptive routing will help in minimizing the possibility of congestion. Now we shall discuss about another type of routing known as multicast routing.

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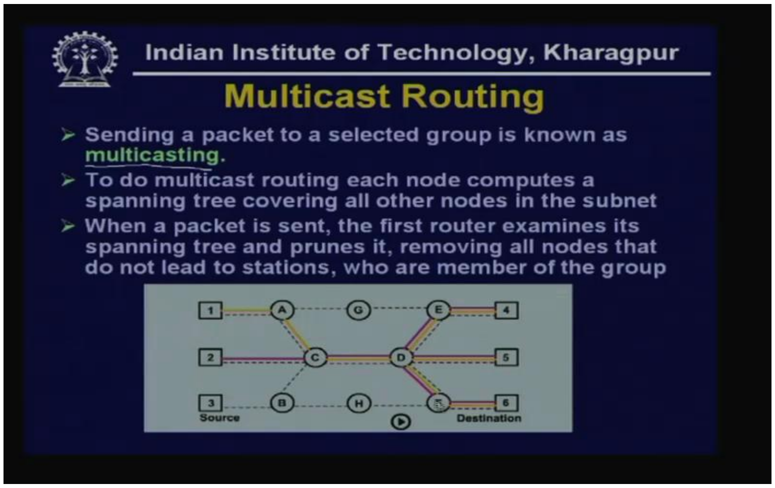

So far what we have done is routing was essentially from a source to a destination between a pair of stations. But there are situations where a particular node will send to a group of stations, a particular station will send to a group of stations. For example, there is a video service provider who is giving video on demand to a group of people. In such a case a particular video may be TV channel or a movie has to go a particular group of users and not to a single user depending on their demand known as multicasting.

So, to do multicast routing each node computes a spanning tree covering all other nodes in the subnet. Let us see how it is being done. In this case 1 2 3 are the sources of different packets (Refer Slide Time: 37:22). On the other hand, 4 5 6 are the designations. Or you may consider that these are the subscribers and these are the service providers. So video signals are going from these three stations 1 2 3 and on the other hand, it is going to 4 5 6 destination stations these are the consumers or users. Now let us see how this spanning tree works.

So here we find a spanning tree from 1 it can go through this path 1 to node A, to node C, node D and from D it is multicasted it is transmitted not in one direction but in three directions because 4 5 6 these four users are the group of stations who want to get the service. Similarly from another source it can be 2 3 and this path is common (Refer Slide Time: 38:32) then it will go to 4 5 6 so from these two stations service can be taken by 4 5 6 so a spanning tree is formed. So we find that when a packet is sent the first router examines this spanning tree and prunes it. So here as you can see after this node A receives a packet may be related to a video then instead of sending to G it prunes it so it simply uses this path and sends it. The direction to which it will send any further is based on the spanning tree. That means from A it will go to C and C also will not send to any other path but it will send only in this direction. So, multicasting is done and spanning tree formation can be done which will decide the route.

Here you can see D will send through all the links because there are subscribers connected to E F and directly to D. this is the example of multicast routing. One very special situation of this multicast routing is your broadcasting. Suppose a particular node has to broadcast some information to all other nodes for that the obvious candidate is flooding. So flooding can be done whenever the broadcasting has to be done for all the nodes.

For example, if this node wants to broadcast something it will do the flooding and it will reach all the stations so in that case the routing algorithm will be simple and there will be no need to form spanning tree and the process needed for each of the node will be smaller. However, we already know that the limitations of flooding will be there but it is a very robust technique for broadcasting. That is why flooding is used in many situations for broadcasting purpose.

Now we have discussed various routing techniques both static and dynamic. Now let us take up a case study. We shall study the Arpanet network and we shall see how the routing technique has evolved in Arpanet gradually.

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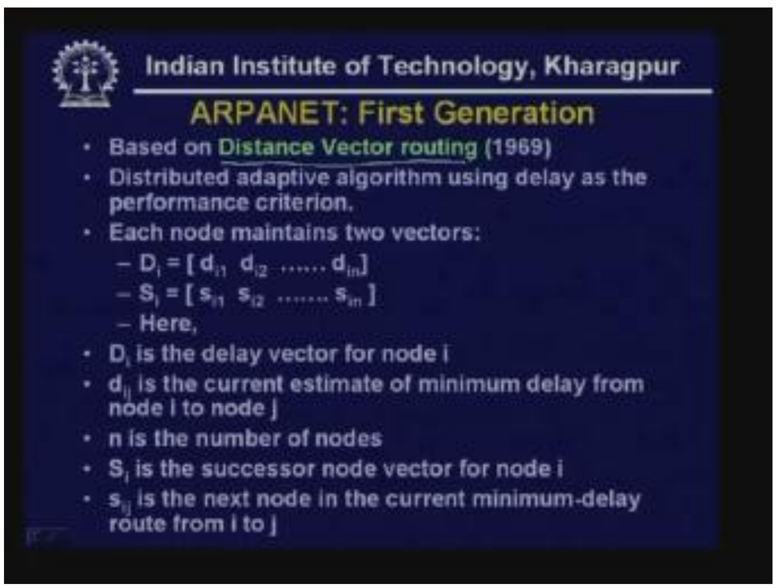

Arpanet is Advance Research Project Agency Network which is the foundation of the present day internet. Many tools and techniques have been developed in Arpanet which are still being used present day context. The first generation algorithm was based on Distance Vector routing which was developed sometime in 1969. So this first generation algorithm is a Distance Vector routing and it is a distributed adaptive routing so there is no central controller and all the nodes take part in routing so it is a distributive adaptive algorithm using delay as the performance criteria. so each node maintains their Distance

Vector as you can see it maintains two vectors Di is equal to di1, di2, din so this is one vector essentially this is the delay information for sending packet to node 1 2 to n and S the si gives you the successor node vector to node I. so here as you can see the list of successor nodes are given as si1, si2 and si_n to successor node Qi to where packet has to be forwarded for sending to destination 1, 2 and n.

So here Di is the delay vector, dij is the current estimate of the minimum delay from node I to node j. that means from node I to node 1, 2, n this vector is stored. Similarly xij is the next node in the current minimum delay route from I to j. that means based on the delay information the next hop node is calculated and these two vectors are stored in each and every node. Obviously for doing that some calculation has to be done. Periodically each node exchanges its delay vector with all of its neighbors.

As we have seen in Distance Vector algorithm we already discussed that exchange of information takes place with the neighbors but not with all the nodes so that is being done here. And the interval as you can notice it is very frequent at an interval of 125 millisecond. And using the incoming delay vectors node k updates its vectors as follows. So it finds out the minimum delay path for all I in A using skj is equal to I using I which minimizes the expression above. So the minimum value is calculated and here A is the set of neighboring nodes from k and iki the current estimate of delay from k to I. So the minimum value is taken as the delay information which is being used to compute the least-cost path may be by using Bellman-Ford algorithm.

Here the estimated link delay is simply the queue length for that link. Suppose this is the particular node (Refer Slide Time: 44:58) and these are the out links so the queue length for each of these links is being used as the representative of the delay. So, in building the new routing table a node will tend to favor outgoing links with shorter queues. In the link in which the queue length short obviously whenever the routing table is made a node will tend to favor the outgoing links with shorter queues. Since queue lengths vary rapidly with time a thrashing situation may result. So whenever this thrashing situation occurs because by the time the next routing table is formed and packet is forwarded that queue length gets changed. So what can happen is again routing calculation has to be done so a packet continues to seek out areas of low congestion rather than aiming towards destination.

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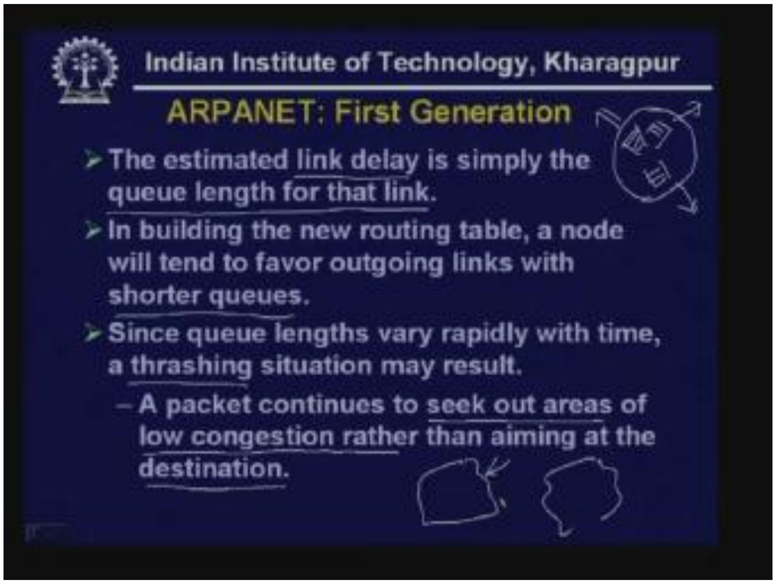

Suppose this is the part of the subnet so initially in this part of the subnet the packets are forwarded in this direction because of smaller queue so there will be congestion here and whenever it is found that queue length has increased it is forwarded in this direction so there will be congestion here also instead of going towards destination. Hence this congestion is known as thrashing. So this is the problem that arise Arpanet first generation network. So whenever the second generation approach was decided the drawbacks of the first generation algorithm were evaluated. The drawbacks are only queue length were considered and not the line speed. Of course when the first generation technique was developed in those days the links were of low bandwidth low data rate. However, when the second generation algorithm was considered by that time the links have been upgraded from low rate to high rate and as consequence it was necessary to take into consideration the line speed.

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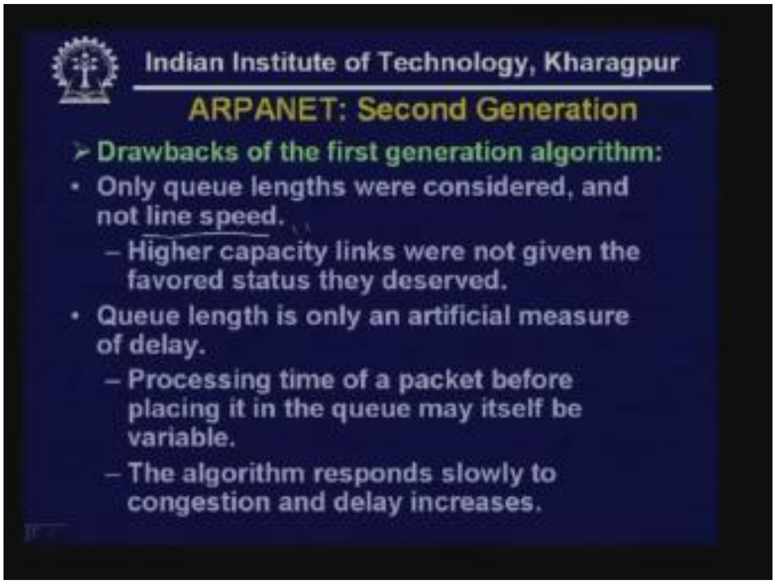

The queue length is only an artificial measure of the delay it cannot be a correct representative of the delay and processing time of a packet before placing it in the queue may itself be variable. That means the queue length may change by the time processing is being done by a node to send it in a particular queue so the algorithm responds slowly to congestion and delay and as a consequence delay increases. These are the limitations which were identified when the first generation algorithm was considered and second generation algorithm that was proposed in 1979 after two years shifted to link state routing. They modified the Distance Vector routing to a link state routing. So here also link state routing is also a distributive adaptive algorithm but which uses the actual delay as the performance criteria rather than the artificial delay based on the queue length. So the delay is measured directly by time stamping the packets using positive acknowledgement.

For example, if a node receives the packet that incoming time is known as time stepped and the time it is going out is also the time step. The difference of that is added with the transmission time and the propagation time of the packet to get the information about the delay and that delay is being used for the purpose of computation. Here as you can see it is compare to 120 millisecond and at every ten second a node computes the average delay on each outgoing link. As I mentioned earlier in link state routing the interval is significantly increased from 128 millisecond to 10 second. So, at the interval of 10 second by flooding the information exchange takes place. And since the interval is quite long this will not affect the performance of the network that much.

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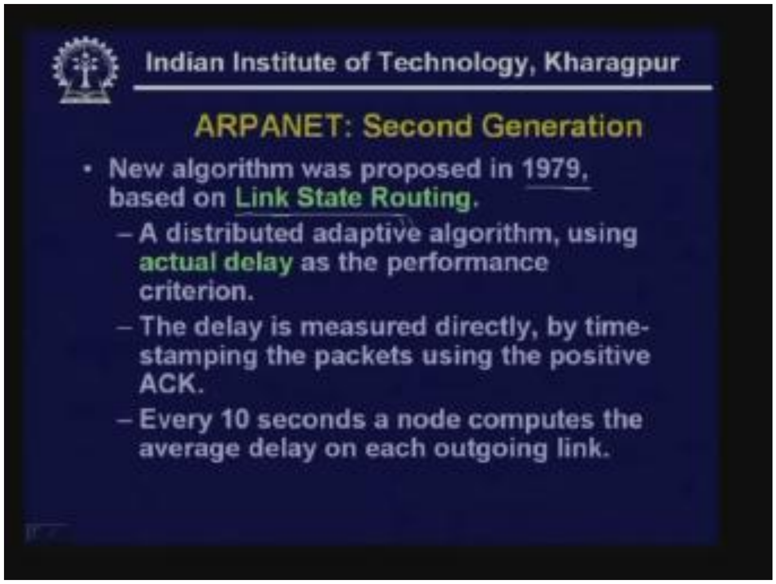

By using this second generation algorithm by measuring the actual delay the performance was significantly improved. However, when it was again reviewed in the year 1989 it was found that problem with the previous approaches was that every node was trying to obtain the best route for all destinations, and that effort is conflicted.

That means since all the nodes were trying to forward in the direction of the least-cost path and best effort routing was done which was leading to some problem. Whenever the node is lightly loaded, network is lightly loaded it works fine. However, under heavy load condition this best effort routing or routing in the least-cost path direction does not work so well. So the goals of routing are to give the average route a good path instead of attempting to give all routes the best path. So, instead of using the best paths the good path was computed. The basic approach was not changed, however there was a change in policy, instead of forwarding towards the best path it was rather forwarded towards good path and as a result the network or the subnet towards the best path will not congested.

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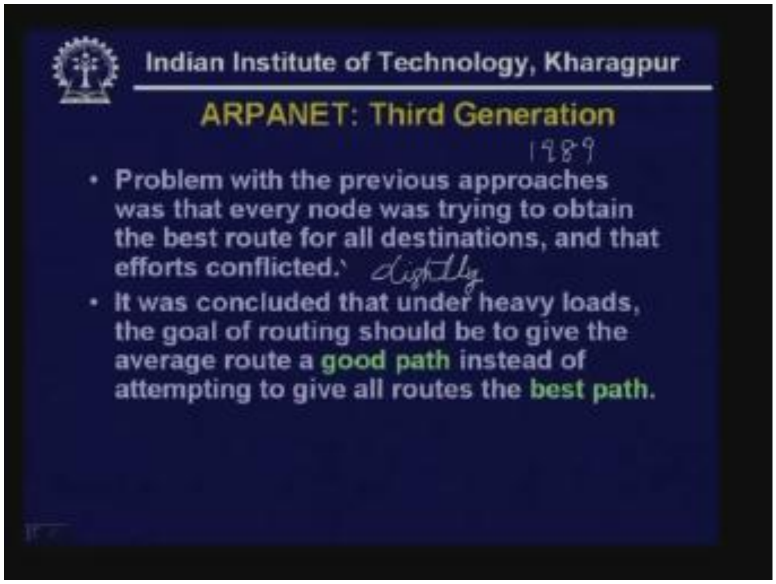

So the designer decided that it was unnecessary to change the overall routing algorithm. It was sufficient to change the function that calculates the link costs. So link cost calculation was done in a different way. It was done in a way to damp the routing oscillations. As I said the congestion producing oscillation are stopped here such as damp oscillations and reduce routing overheads. It uses simple concepts from queuing theory. So queuing theory was used to find out the link costs. The average cost function is to use utilization rather than the delay. Here earlier delay was used as the main parameter. higher however the utilization was considered as the main parameter so whenever the load was small it was essentially based on that Distance Vector routing, it was somewhat like this. That means as utilization is initially small it was based on the Distance Vector routing and then as the utilization increases it goes in this region (Refer Slide Time: 53:10). Here for example utilization is 1, it is normalized 100%. So whenever it goes in this region based on utilization it switches to that link state routing. As a consequence there was significant improvement in performance. We have discussed about Arpanet and we have seen how the routing strategy has evolved in Arpanet. Now it is time to consider the review questions.

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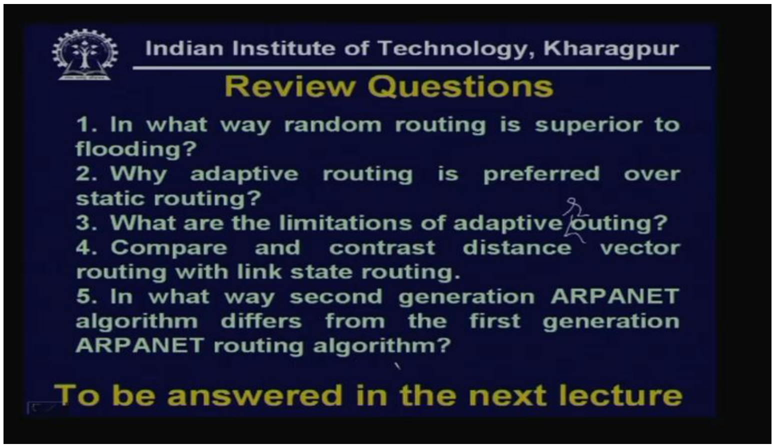

1) In what way random routing is superior to flooding
2) Why adaptive routing is preferred over static routing
3) What are the limitations of adaptive routing?
4) Compare and contrast Distance Vector routing with link state routing
5) In what way second generation Arpanet algorithms differs from the first generation Arpanet routing algorithm?

These questions will be answered in next lecture. Here are the answers to the questions of lecture minus 12.

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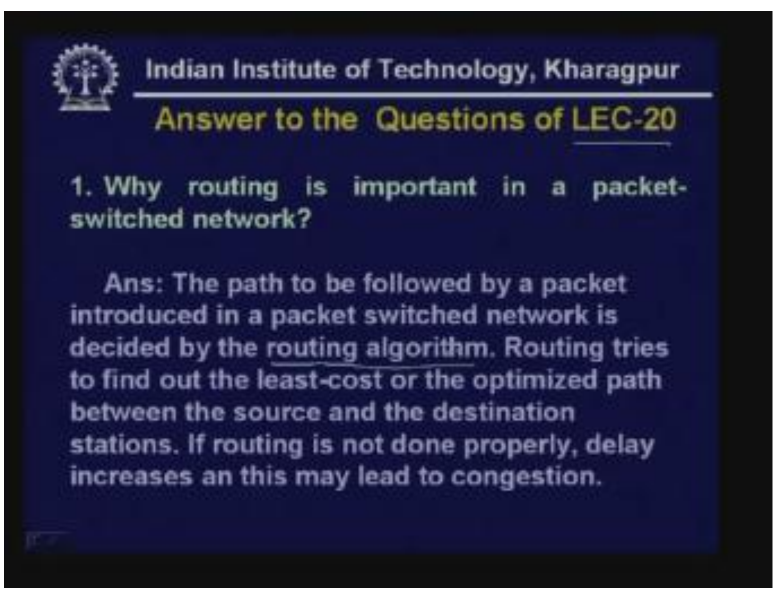

1) Why routing is important in packet switch network?
The path to be followed by a packet introduced in a packet switched network is decided by the routing algorithm. Since the packets will be making several hops before it reaches

its destination routing is very important and routing tries to find out the least cost or the optimized path between source and destination stations. If routing is not done properly delay increases and this may lead to congestion.

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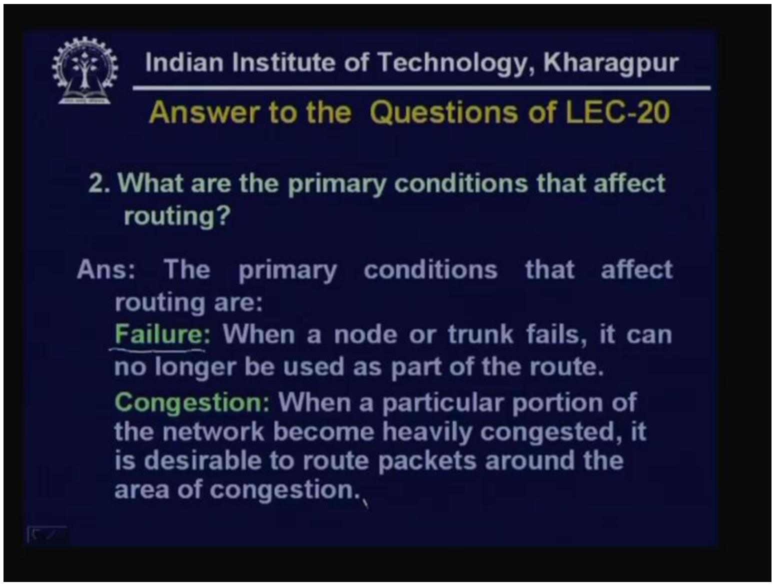

2) What are the primary conditions that affect routing?
As I have seen if there was no change if everything was static then static routing is good enough. However, there are two important factors that changes. One is failure. Whenever a node or trunk fails it can no longer be used as part of the route so we have to go for dynamic algorithm and second aspect is congestion. So whenever a particular portion of the network becomes heavily congested it is desirable to route packets around the area of congestion rather than through the congested area. These are the two primary conditions that affect routing and routing strategy has to be changed whenever these two happen.

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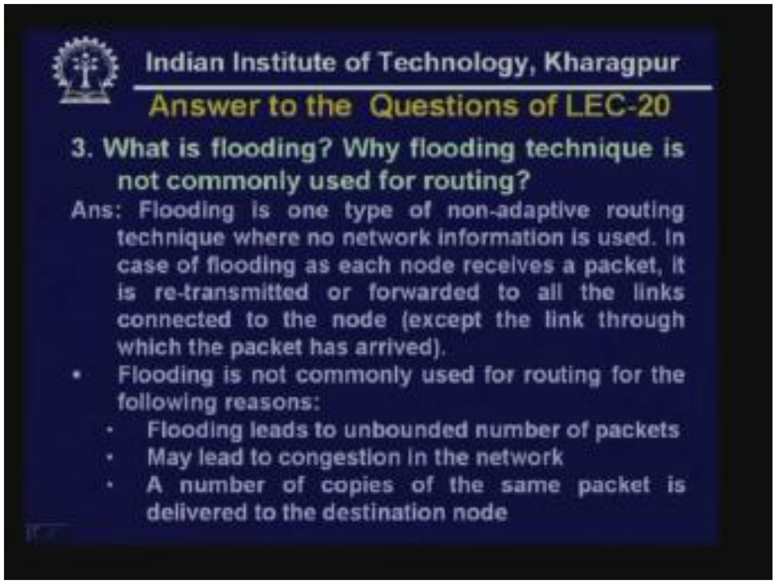

3) What is flooding? Why flooding technique is not commonly used for routing?
As you know flooding is one of the non adaptive routing techniques where no network information is used. In case of flooding each node receives packet it is retransmitted or forwarded to all links connected to the node except the links through which the packet has arrived. Flooding is not commonly used for routing for the following reasons. As we know flooding leads to unbounded number of packets, it may lead to congestion in the network and a number of copies of the same packet is delivered to the destination node. These are the limitations.

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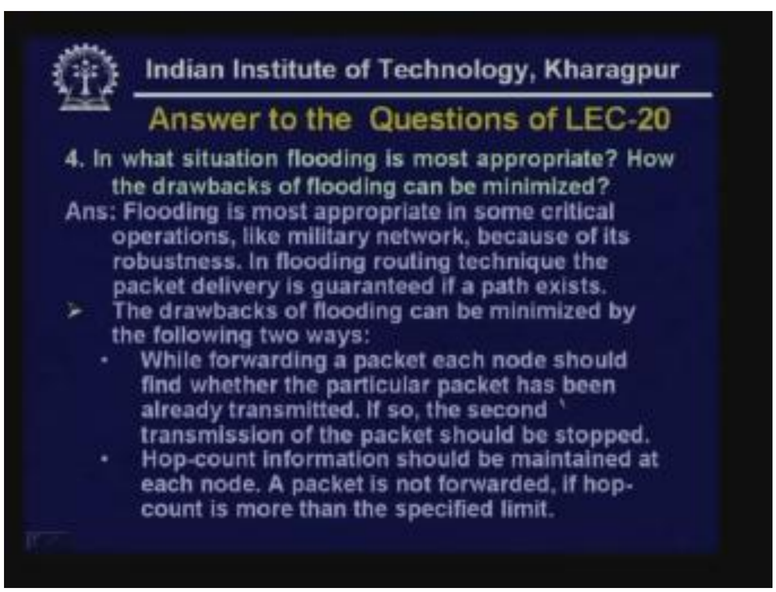

4) In what situation flooding is most appropriate? How the drawbacks of flooding are minimized?

Flooding is most appropriate in some critical operations like military network because of its robustness. In flooding routing technique the packet delivery is guaranteed if a path exists. The drawbacks of flooding can be minimized by the following two ways. As we have seen one can be done while forwarding a packet. Each node should find whether a particular packet has been already transmitted and if so the second transmission of the packet should be stopped. Another is hop count. Hop count information should be maintained at each node. A packet is not forwarded if hop count is more than the specified limit. With this we come to the end of today's lecture, thank you.