Computer Networks And Internet Protocol
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Lecture – 26
Network Layer I – Introduction

Welcome back to the course on Computer Network and Internet Protocols. So, till now in the course we have looked into 2 different layers of the TCP IP protocol stack; the application layer and the transport layer. So, from now onwards we will look into the third layer of the protocol stack from top to bottom direction; that is the network layer or sometime people call it as the internet layer of the protocol stack.

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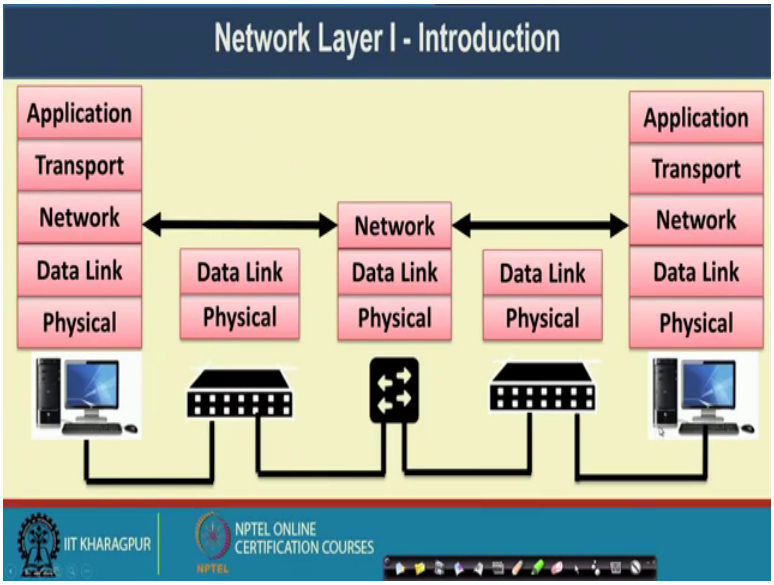

So, as I looked earlier that this network layer at the internet layer of the protocol stack, it interconnects multiple devices in the network or we call that they are kind of the layer 3 devices; which actually take care of 2 forwarding the data packets from one end host to another end host. So, the broad objective of this network layer or the internet layer of the TCP IP protocol stack is to ensure that wherever you want to forward the packet, the packet is successfully delivered to that particular destination. Or the network will try it is best to deliver the packet to the destination.

Obviously this network layer or the internet layer it does not able to guarantee the successful delivery all the time in a packet switching network, because in a packet

switching network. There is always a possibility of having a packet drop. And that is why we have looked that in the transport layer of the protocol stack we take care of the reliability and order end to end aspect.

But in the network layer we will primarily look into that given a particular destination for a data packet, how will you ensure that the particular packet is delivered to that destination which is mentioned by the application developer.

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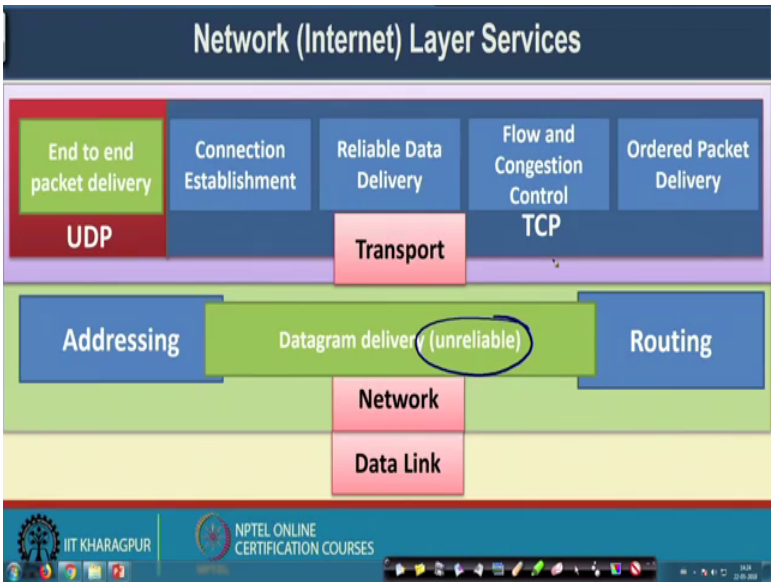

So, we will now at the middle of the protocol stack and we will look into the details of this network layer and the internet layer. So, coming to the network at the internet layer, so, let us look into the different services which are being provided by this particular layer of the protocol stack. So, we call it as the layer 3, because from bottom up it is at the third layer it is in the middle of all the layers of the protocol stack.

So, this network layer as we discussed earlier that from data link layer it gets certain services, or the data link layer it ensures that well how will you transfer a data packet or a frame in the terms of data link layer; from one node to the next node which is directly connected via wire or there in the communication range or wireless communication range of each other.

So, the data link layer takes care of forwarding the packet directly to the next hop. Now, whenever in your internet your destination is connected via multiple such hops and the

entire network looks like a graph. In that particular graph, the challenge comes that how will you find out a good path to forward your data packet from the source node to the destination node. So, that is taken care of by the network layer of the protocol stack that we are going to discuss.

So, this network layer of the protocol stack ideally it supports this datagram delivery. So, in network layer we call the unit of data as the datagram. So, this is a kind of unreliable data gram delivery in the context of TCP IP protocol stack and for the context of packet switching network, because as we have learned earlier that in case of packet switching. There is no guarantee that you have sufficient pace, that will be there in the intermediate buffer or the network buffer.

So, there is always a possibility that those particular packets, those will get dropped from the network buffer and a loss of data packets. So, that is why we say that the network layer it tries it is best to deliver the packet to other end host. So, that is why we use the term unreliable to introduce the delivery model which is being used at the network layer.

So, the network layer ensures unreliable datagram delivery which is a kind of what we normally say as the best effort service to tries it is best to transfer the data packet from the source to the destination, via multiple such hops.

And then on top of that in the transport layer you have multiple services that we have already looked into, that in case of the transport layer, if you are going to use a TCP kind of protocol. So, the TCP kind of protocol will ensure the reliability by utilizing the retransmission of the data packets. So, that we have already looked into.

So now in case of a network when the network is represented in the form of a graph, that we have looked into the initial lectures, that in that network graph there can be multiple hops or multiple paths between a source and the destination.

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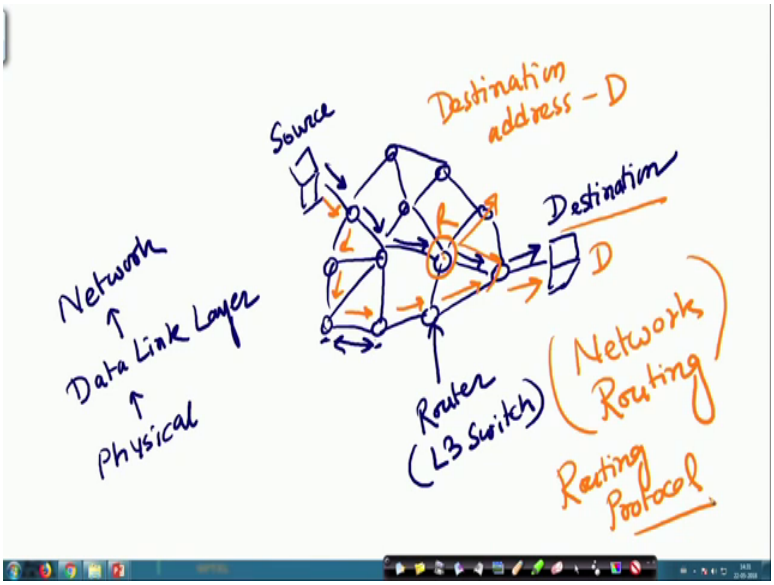

So, ideally a network if you look into it is graph structure, it will look something like this. So, you have multiple nodes there which are interconnected with each other.

So, the nodes are interconnected with each other, these links can be wired links or this can be wireless links as well. And then you have one source in the network and one destination in the network. So, this is my source and this is my destination.

Now, the data link layer of the protocol stack that is the layer 2 of the protocol stack. So, if you remember the different layers of the protocol stack at the bottom we have the physical layer; which takes care of physical signal transmission, on top of the physical layer we have the data link layer. So, this data link layer of the protocol stack, it ensures that how will you deliver the data from one hop to the next hop; which are directly connected with each other.

So, that is the task of the data link layer or that is the services, which is provided by the data link layer to the next layer that is the internet layer or the network layer of the protocol stack.

So, then the data link layer provides a service to the network layer, to forward the packet in one hop distance. So, where, the 2 nodes are directly connected to each other. Now whenever you are going to the network layer and you need to forward a packet from the source to the destination and your entire network can be represented as a network graph,

where each of these circles or each of these nodes represent a network router or sometime we call them as l 3 switches or the layer 3 switch.

So, whenever they are connected via this layer to switch or the router. And these routers they have up to layer 3 implementation; that means, up to network layer implementation. And in that case you can see that if you want to forward the packet from this source to this destination, there are multiple paths which are possible. So, one path is like you can follow this particular path to forward the packet from the source to destination. Or you can follow another path say this path to forward the packet from the source to the destination.

Now, ideally this blue path is a smaller path. So, if you would metric or if you decide to forward the packet in the lowest hop path or the minimum hop path then you will prefer this blue path. But minimum of path may not be always give you the optimal performance. Because it may happen that your minimum path has the a very low capacity low end to end capacity.

If your minimum path has a very low end to end capacity and if you push all the packets in that particular path, then there can be a degradation in end to end packet forwarding performance. So, that is why in a typical network we do not always prefer to use the minimum hop path. There are other various metrics which are available, based on which we decide that how to forward a packet from one node to another node.

Now, in this entire thing the good thing is that if you have this entire topology available and the link characteristics available. So, if you have this whole topology available along with this link characteristics available. Then possibly you can apply certain graph algorithm like the shortest path algorithm that you have learnt in your algorithm course, like that Dijkstra's algorithm or bellman ford algorithm to find out the shortest path.

And where this metric that you want to use to decide the best path, that will work as the weight of a particular link. And that way if you can represent this entire network in the form of a central graph structure then you can execute the bellman ford algorithm or Dijkstra's algorithm to find out the shortest path and then forward the packet through that shortest path.

But unfortunately in our network we do not have this facility available. Because all these individual routers at the layer 3 devices, they work in a complete decentralized way. So, every individual router or every individual layer 3 device, need to take care of or need to decide that how to forward a particular path packet to the next hop; a given destination addresses available.

And you do not have any central coordinator or centralized system which will monitor this entire network topology and give you a central graph in the in the form of your network topology structure.

Because our network works in this kind of decentralized way, the network layer has a huge job to find out that how will you decide that what is your next hop, which will give you the optimal end to end path based on the path metric that you have chosen. So, this particular methodology is termed as network routing.

So, the routing procedure decides that at every individual hop, every individual intermediate router whenever you are receiving a packet with this particular destination what should be your next hop and that is done in a completely decentralized way.

So, this particular router R need to decide. So, once it receives a packet, say I am giving or I am assuming that the address of this particular destination is d; later on we will see that how we represent this particular addresses in network layer. So, if you receive a packet at R with a destination address as with destination address as D, then you have to decide that what should be the suitable next hop to forward that packet; whether you want to forward that packet to this router or whether you want to forward this packet to this router.

So, that is the task of the prime task of the network layer. So, the network layer need to design a particular protocol which we call as the routing protocol to make this decision in the internet. So, that is the broad objective of the network layer.

Now, in network layer this unreliable datagram delivery service; which is being provided that has 2 primary basis. One is first you have to uniquely identify every individual host in the network. And for that you need to have one addressing mechanism. So, first we will look into that at a typical internet how we individually identify particular node.

So, you can you can here you can think of this entire packet delivery in the network in the form of our normal mail delivery or the postal mail delivery. In case of our postal mail delivery you require a particular addressing format. In you in that address you have your name followed by your, house number followed by your locality name of your locality, then the name of your village or the city a particular pin code, then the name of your state finally, if you are making a international postal mail transfer the name of your country.

So, all these till this entire address actually hierarchically determined that who had to forward that particular postal email. Similarly, in the network whenever we talk about the addressing scheme we have to design this addressing scheme in a hierarchical way. So, we will go to all these details sometime later, but the basic message that I want to give to you is that, this entire packet delivery in the network it follows the similar principle of what we apply in case of our postal email delivery.

So, we have a addressing concept a particular addressing format that need to be used to forward the data packet or the that need to be used to uniquely identify every individual node in the network. And then you need to have one routing mechanism, to decide that given a destination address, how will you forward the packet over the network, over multiple hops so that you can be able to successfully deliver the packet to the final destination.

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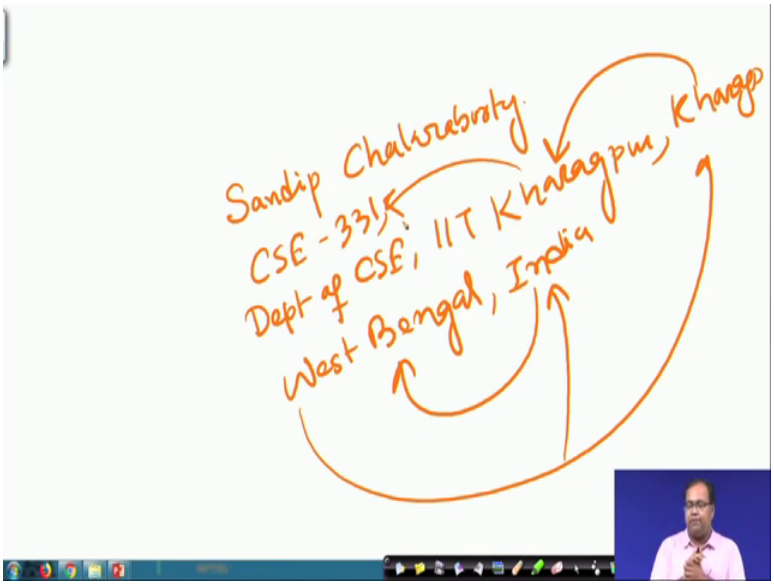

So, if you try to compare it with the normal postal mail delivery system, so, in case of your postal mail delivery system, say if my postal. Mail id is that say Sandip Chakraborty; that means, my name followed by say my office number, then department of CSE IIT, Kharagpur, West Bengal, India.

Now, this is my postal mail address and in this postal mail address there is a kind of hierarchical notion. So, whenever someone is wanting to forward a postal mail to my address, they have to fast forward it to the say head post office of India. Then from there it will be forwarded to West Bengal, from there it will be forwarded to say Kharagpur. From Kharagpur it will be forwarded to IIT, Kharagpur and then finally, it will be forwarded to my office which is in my name.

So, that way in a hierarchical way this entire postal mail is being forwarded. And whenever we apply this routing mechanism over the internet we also apply this kind of hierarchical concept. So, in this entire discussion of network layer protocols we will look into that first of all how will you individually identify every host with certain address which has this kind of hierarchical nature and number 2 given a address in this hierarchical format how will you decide where to forward a particular packet.

So, that are the broad services which are being provided by the network layer or the internet layer.

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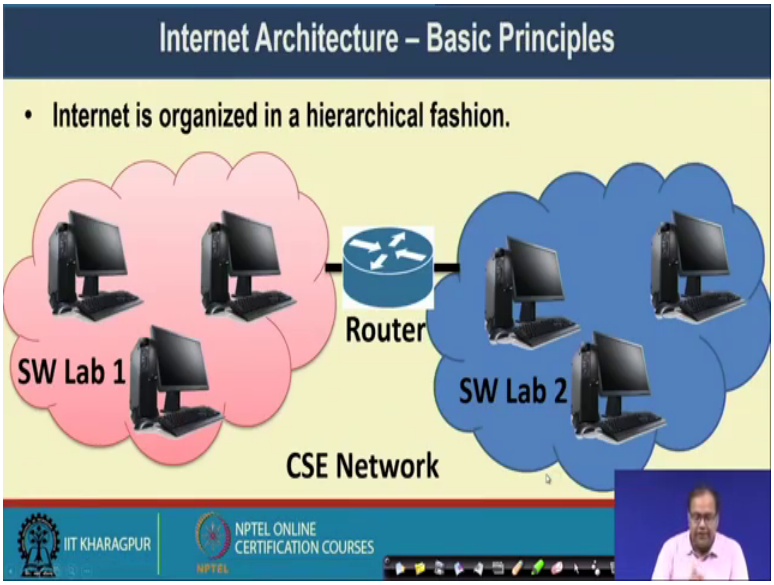

Now let us briefly look into this entire internet architecture because that has the notion or that has the concept which you will require to identify or to understand that how a packet is being forwarded between 2 machines. Say, whenever you are accessing dub dub dub dot google dot com your google machine is possibly residing somewhere in USA and you are trying to connect it. Say if I am trying to connect to google machine right now, I will be connecting that google machine which is residing at USA from a machine which is there in Kharagpur.

Now, from Kharagpur to USA how will you forward the data packet that is our concern. So, for that let us look into that how this entire internet is organized in a hierarchical way, that will give you they give us an intuition about how will you actually address a particular machine in the internet. So, I am I am just starting from a very small network then gradually I will increase the network in size. So, let us start with a 2 different laboratories in our computer science department at IIT, Kharagpur. So, we have 2 different software labs software lab 1 and software lab 2.

So, in software lab 1 we have certain set of desktop on software lab 2 we have another setup desktops. Now, this software lab 1 they form a local area network, because they are connected by layer 2 devices or the layer 2 switches, they are directly connected in one hop distance. So, therefore, they form a local area network. Then the software lab 2 they form another local area network by connecting the machines through one layer to switch.

Now, these 2 software lab 2 software lab 1 and software lab 2, they are connected with each other via layer 3 or a router. So, this router here is a layer 3 switch or a layer 3 device, right. Now, here by connecting to different local area network or lan 1 and lan 2 I have constructed one network which is the computer science and engineering network at IIT, Kharagpur.

Now, from here if we further expand the network; so, we have multiple departments in the institute in IIT, Kharagpur.

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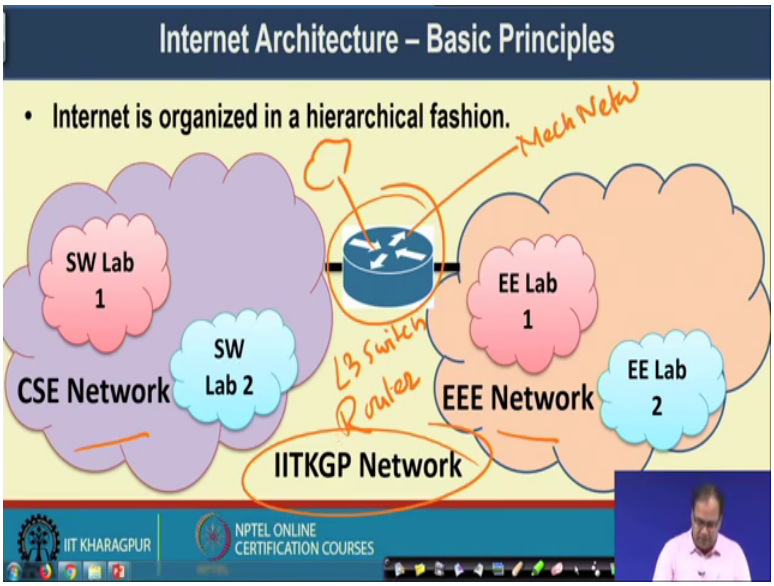

So, every individual department have their networks. So, that way we have constructed the CSE network the computer science department network; which has the software lab 1 software lab 2 and they may have another network like the faculty network the student network, the research lab networks, all these form under this CSE network they are connected by individual layer 3 routers. And then I have this network at the electrical department EEE network, there you we have 2 different labs e lab 1 and e lab 2 in the similar fashion that the CSE network is connected with.

Now, this 2 network the CSE network and the EE network. They are again connected via another router or another layer 3 devices. So, this is my layer 3 switch or the router which is connecting the CSE network with the EEE network and this entire network; that means, the individual departmental network. So, this is just a snapshot of the example so that way I have multiple other networks like say, mechanical network, the mechanical department network, then different home network or the administrative network.

So, all this different network which are there inside IIT, Kharagpur, they are getting interconnected with each other with this layer 3 switches or routers and they form the entire IIT, Kharagpur network.

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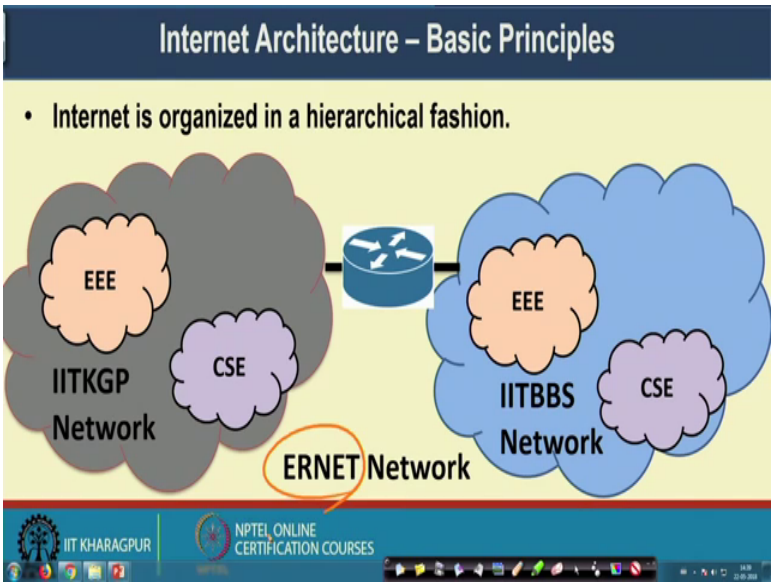

Now in India we have multiple such institutes. So, in IIT, Kharagpur we have this way one network, then in IIT, Bhubaneshwar there is another network. Every network has this way the hierarchical way in a top down approach.

Now, these 2 network the IIT, Kharagpur network IIT, Bhubaneshwar network as well as say IIT, Mumbai network IIT, Kanpur network all those networks are connected with each other through multiple such again layer 3 devices or the routers and they formed a ERNET network. So, education and research network of India. So, this ERNET it is basically government initiative to interconnect different such networks or different educational institute altogether. So, we call it as educational and research network of India so that way the name ERNET came from.

So, these ERNET network they interconnects all these different network together.

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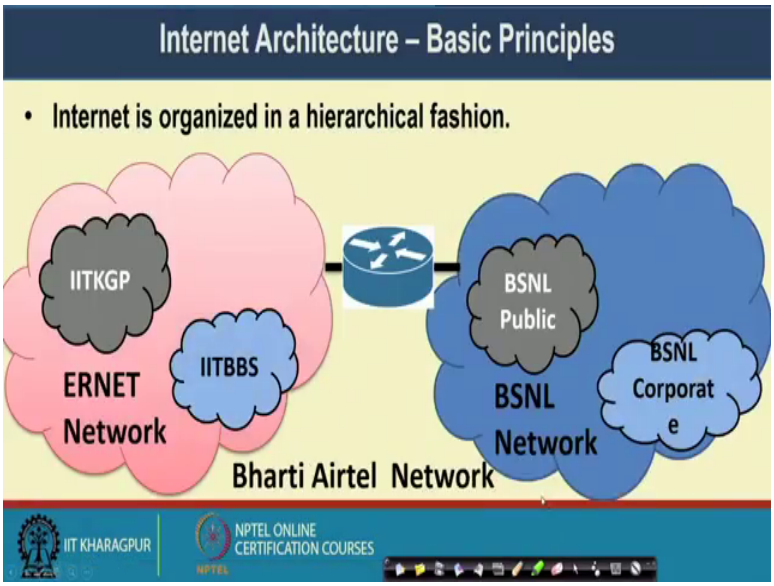

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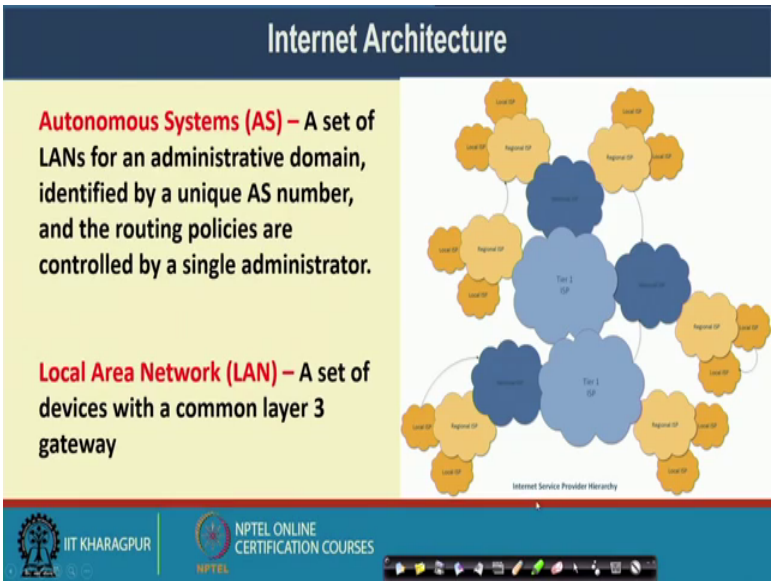

Now if we again go up to the hierarchy I have this ERNET network which interconnects multiple such institutes and several other networks; say, the BSNL network. So, this BSNL network has their public network and the corporate network you have the Airtel network you have say Vodafone network; all these networks they are inside internet they are again connected with each other. And they get the service from in India from Bharti Airtel.

So, all of them are connected under this Bharti Airtel network. So, that too it is entire internet architecture they follows a hierarchical fashion or a hierarchical architecture. So, that is the thing that is the entire architecture of the internet and inside this internet the individual network that we are talking about; where the network is solely managed by one administrator or one or multiple administrators we call them as autonomous system.

So, formally an autonomous system is a set of local area network for an administrative domain, identified by a unique autonomous system number and the routing policies are inside that autonomous system are controlled by a single administrator. Now in internet one interesting idea is this routing policy, that so, as I have mentioned earlier that whenever you are deciding about how to forward your packet from one machine to another machine. And if you represent this entire internet in a graph structure, then the interesting factor comes that how will you assign the link weight, that what will be your metric for deciding the best routing.

Now, this metric for deciding the best routing that can be independently chosen by the corresponding network administrators. So, that is why in case of the definition of autonomous system, we say that this routing policies they are controlled by a single administrator. So, in general inside an autonomous system we follow a single routing policy, but well there can be autonomous system where multiple routing policies are followed altogether. And this entire ISP structure they form a nice hierarchical architecture.

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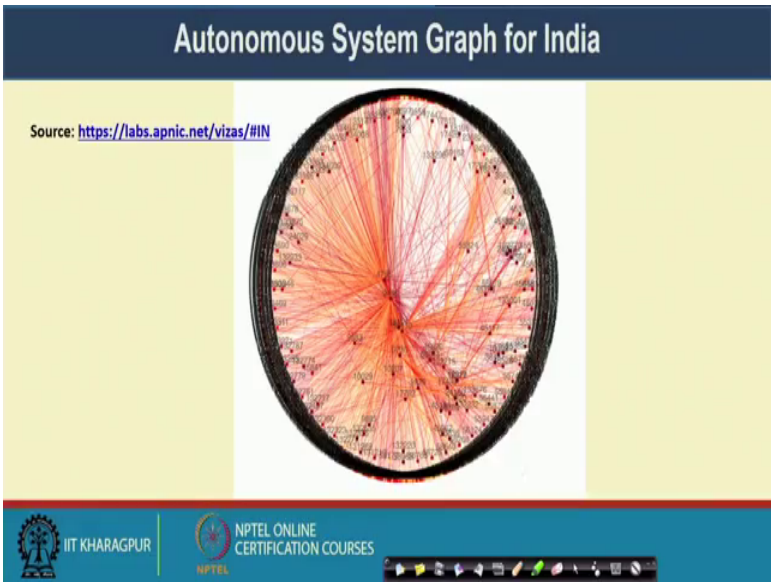

And if you look into this autonomous system graph for India it looks something like this. So, this edge this dark edges they are actually individual number. So, you can go to this site labs dot apnic dot net.

So, this apnic they actually maintain autonomous system inside India. So, these nodes are the edge nodes edge nodes in the autonomous system and this is the nodes which are there in the middle, this nodes they actually provide service to all other nodes. So, they are the kind of central nodes, from where all the different other autonomous systems they are getting their service.

So, for example, all the educational institutes like all IITs the central universities, they get the service from this ERNET India. So, that way this entire hierarchy is being formed for the autonomous systems.

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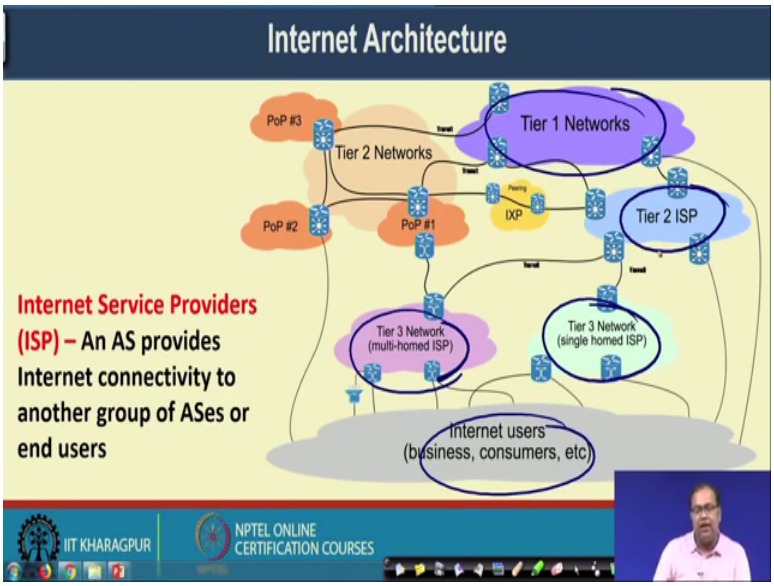

And this tiring architecture looks something like this. So, here we have the internet service providers. The internet service providers are the autonomous system that provides internet connectivity to another group of autonomous systems of the end users.

So, here we have the end users the end users in the internet. Now, this end users of the internet they are connected to certain ISP's; Internet Service Providers, they are kind of tier 3 network or tier 3 autonomous system. From there, so, here we have these 2 tier 3 autonomous systems in this diagram in this particular diagram. So, they are providing services to these internet users.

Now, this tier 3 networks they are getting services from some 2 ISPs, now the tier 2 ISPs they are getting services from the tier one ISPs. So, this tier 2 ISPs say if I just give you an example so, the students inside IIT, Kharagpur they are getting the services from IIT, Kharagpur autonomous system. Now this IIT, Kharagpur autonomous system they are getting services from ERNET India the autonomous system.

Now, ERNET India autonomous system, they are getting services from say Bharti Airtel autonomous system. Then this these are the kind of country level autonomous systems and multiple country autonomous systems are interconnected with each other. And in a tier 2 network we have certain small networks which we call as the point of presence or pop this point of presence are kind of the edge network, which actually takes the service, but do not provide the service to others.

So, these are kind of reserved network or some kind of special purpose network; say for example, the military network. The military network is just used for their internal use and they does not provide services to any other. So, that is a kind of point of presence which is directly connected to the central network of India,.

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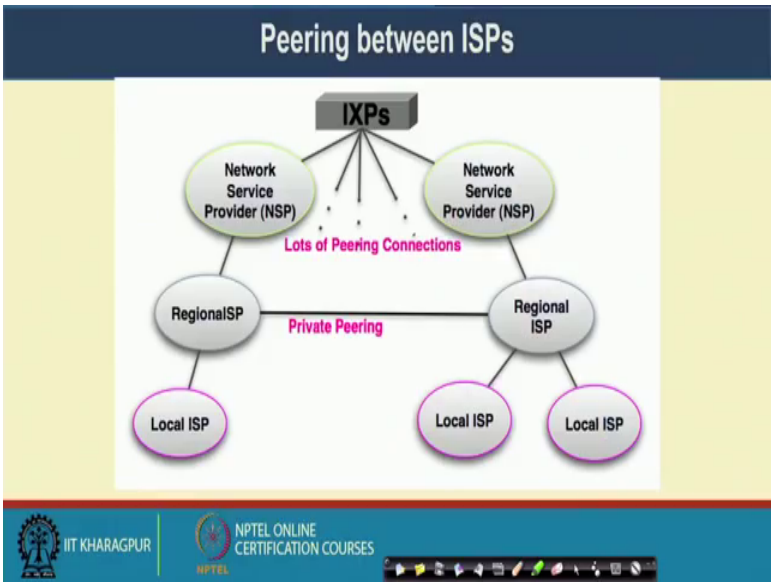

So, this ISPs so, if we just hierarchically try to arrange this individual ISPs. So, at the bottom level we have this local ISPs like this Airtel Vodafone ERNET all these are the kind of local ISPs. Then this local ISPs they get the services from the regional ISPs. So, this regional ISPs they can have connectivity between themselves. So, sometime you have seen that well Airtel announces that well if you use Vodafone and if you try to transfer data from Vodafone to Airtel you will have a lower charge compared to if you try to use some other network.

So, those kind of charge issues they come from this path private peering relationship. So, if 2 service providers they are having private peering; that means, they can directly share the data among themselves which actually reduces the charging policy which is being there in different ISPs. So, those kind of peering we call it or we term it as a private peering. Now this regional ISP, they are connected with the network service provider or the NSP. So, this network service providers are the country level service providers. They are connected to with internet exchange points.

So, all the different national level ISPs or the NSPs they connected with each other globally with this network exchange points. So, this network exchange point actually helps you to transfer a packet from say from India to USA. So, India has one country level ISP or the NSP, USA have one or more country level ISP or NSP. They are connected to this internet exchange point and this internet exchange point, helps you to transfer the data.

So, one example is this the transatlantic lines. So, this transatlantic lines, they interconnect the European continent with the us continent and the through high speed internet or high speed optical fiber cable; which are going through the Atlantic Ocean. So, they are one example of internet exchange point, which actually interconnects 2 different national level ISPs, ok.

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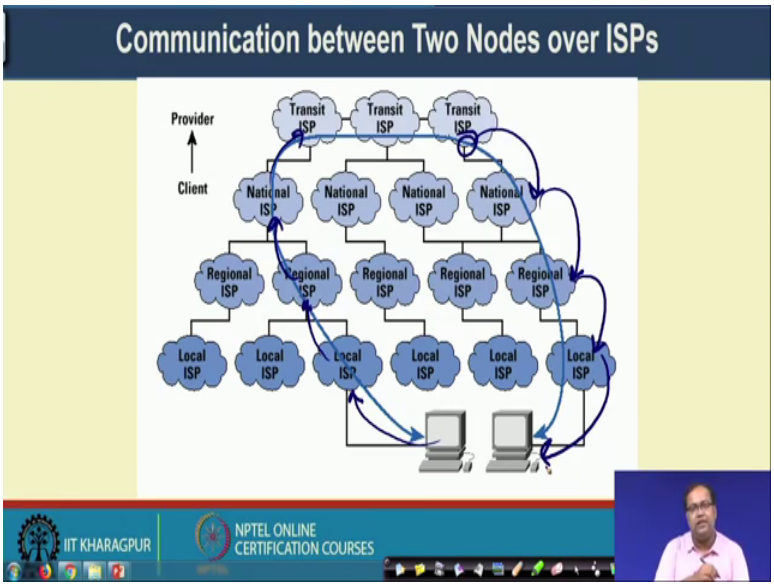

Now, whenever you are forwarding the packet; so, the packet goes in this way so from your machine the packet goes to the local ISP. Now from this local ISP it goes to the regional ISP, from regional ISP it goes to the national ISP or the NSP, from there it goes to the transit ISP. Now, via this transit ISP it reaches to the final destination transit ISP, from there to the national ISP again to the regional ISP to the local ISP and finally, to your destination machine.

So, that way in a hierarchical fashion the packet is being forwarded, the way we forward the normal postal mail. Say, whenever you are forwarding a postal mail from India to

USA. So, you forward it to your local post office; the local post office forward it to the regional post office, the regional post office forward it to the country level central post office; the central post office then forward it to that say the USA post the USA post. Again, in the state level then the regional level then your local level and then finally, that things are getting delivered.

So, the similar concept is being used in the internet. Now all this individual ISPs are nothing but a set of computers which are connected to via lan. So, the initial diagram that I have shown that the way this entire ISP architecture is build up, starting from this software labs in the CSC department to the entire CSC department network and other department then the IIT, Kharagpur network, then the ERNET network and that way the entire thing grows up. So, all this individual ISPs are like that connections of networks.

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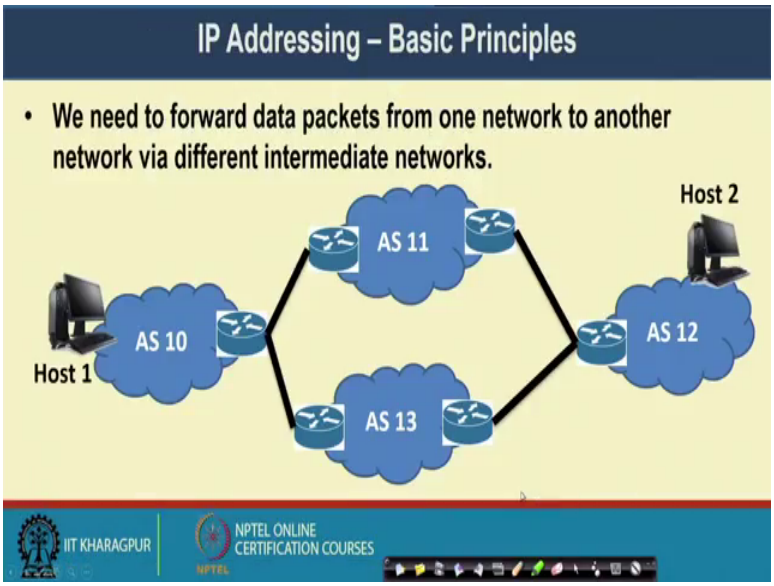

Well, now the thing is that so, the first requirement that we have looked into that, how will you address a particular machine in this kind of architecture. So, this addressed scheme actually comes from this hierarchical concept.

So, whenever you want to forward a packet from say host 1 to host 2, you need to forward the data packet from one network to another network via multiple other such intermediate networks. So, here as I have mentioned that every autonomous system has a unique autonomous system numbers. So, to say this numbers denote the autonomous system numbers 10, 11, 12 and 13.

Now, one host is connected to autonomous system 10 your destination is connected to autonomous system 12. And whenever you are forwarding a packet, you are forwarding the packet from basically from this network the network of as 10 to the network of as 12, via either the network of as 11 or network of as 13. So, whether you are going to use, as 11 as your intermediate network or as 13 as your intermediate network, that will be decided by your routing protocol. So, that is one requirement.

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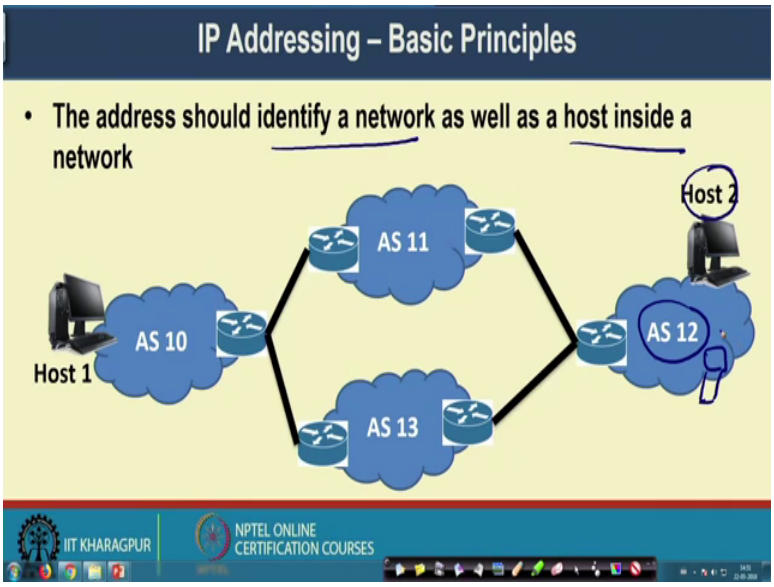

The second requirement the interesting fact is that the address that you are going to provide every individual host, that particular address should identify a network, as well as a unique host inside the network. So, whenever you are forwarding a packet so, whenever you are forwarding a packet say from IIT, Kharagpur to IIT, Bombay the postmaster first need to understand IIT, Bombay.

So, once the mail is being delivered at IIT, Bombay local post office; from IIT, Kharagpur post office dinner then the Bombay post office will try to uniquely identify that person inside IIT, Bombay and deliver the mail to that particular person. So, similar concept is applied here. So, the faster network will try to find out that well this particular host is inside as 12.

So, I need to forward the packet to as 12. So, once the packet is being forwarded to as 12, then you have to uniquely identify that which host inside as 12 need that packet or is the final destination of that packet.

So, that is why, the network address that you are going to design, that should identify the network as well as the host inside the network. So, you can have multiple host inside autonomous system 12. So, you have to identify autonomous system and at the same time this individual hosts inside autonomous system.

So, in the next class, we will look into that how we can use a hierarchical addressing mechanism in network layer based on that widely used network protocol that we call as the IP protocol or IP to design such kind of address. So, see you again in the next class.

Thank you.