Computer Networks and Internet Protocol
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Lecture – 41
IP Routers

Welcome back to the course on Computer Networks and Internet Protocols. So, till now we have looked into the IP routing mechanism in details and we have looked into the IP address in format, how routing works and different type of routing protocols which are implemented over the internet. So, today we will look into the device in details that support routing.

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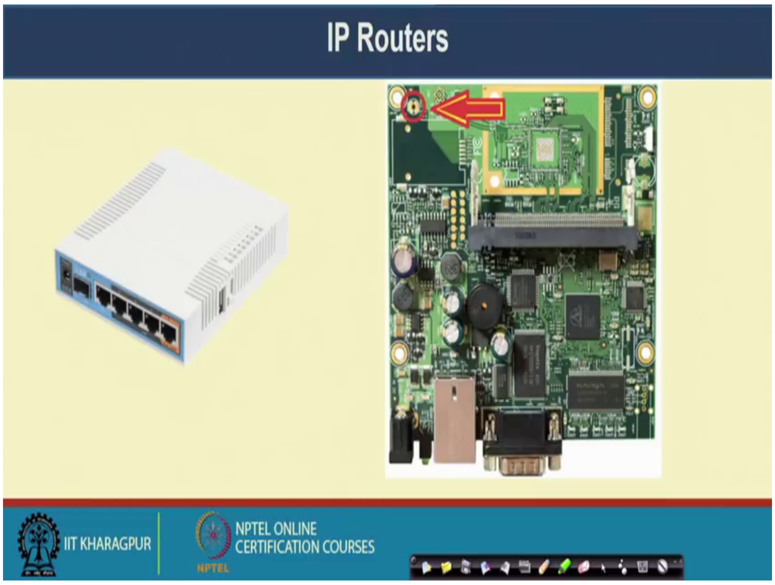

So, we will basically look into the design of an IP Router that how an IP router looks like, what are the different components inside an IP router and how you can design and optimized IP router with the help of different hardware platform. And in the next couple of classes, we will also go for a demonstration about IP router to show you a practical router and its different components which are there inside it and how can you configure it and how can you process different components which are there inside the router. So, let us look into the design of a router in details.

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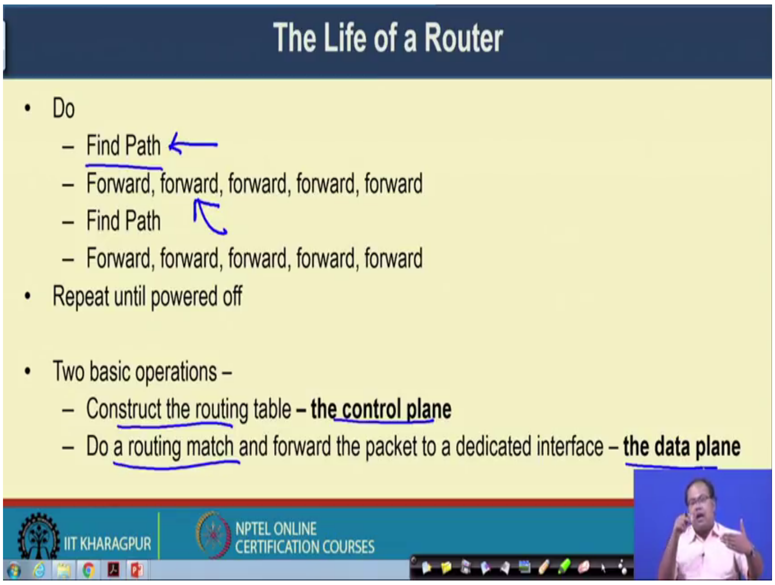

So, if you look into the lifecycle of a router apparently it is very simple. So, the lifecycle of a router is that you can represent it in the form of do repeat loop. So, you find a path to a particular destination, then you forward, forward, forward, forward, forward multiple packets to that destination again whenever a new destination comes you find out the path and then forward, forward, forward, forward the packets to that destination until the router gets powered off.

So, from this simple loop functionalities you can see that there are two basic functionalities of an IP router. So, the functionalities are first finding a path and then doing forwarding. Finding a path means you need to execute a routing protocol. As we have looked into earlier there are multiple type of routing protocols the inter domain and intra domain routing.

In case of intra domain routing we have looked into there are distance vector routing protocols, the link state routing protocols and in protocol format the routing information protocol or OSPF protocol and for inter domain routing we have the border gateway protocol at the BGP. Now, this routing protocols will help you to execute this task to find out the path and then the actual forwarding comes and the actual forwarding means, you have the routing table where you have this entire information.

So, once you have constructed the routing table and you have a packet incoming packet, you look into the header part of the packet, find out the destination IP address, from the destination IP address you make a match with the routing table, find out the next top and forward the packet to that next top.

So, that is the part of the forwarding engine. So, accordingly we actually have this 2 basic operations; construction of the routing table to finding out a path. This part of the router we call it as a control plane of the router which actually controls the entire forwarding mechanism and then do a routing match and forward the packet to a dedicated interface that part we call as the data plane part of the router.

So, the control plane of the router it takes care of finding a path and the data plane of the router it takes care of making a match with the routing table and then a forward the packet to a interface which will transfer the packet to the next top. Now, in this entire architecture there is an interesting observation.

The observation is that, the functionality of the control plane it is kind of periodic; periodic in the sense like, you will find out a path to a destination only when you will get a new packet where the information is not available in the routing table. During that time you will execute a routing protocol or in case of link state routing or OSPF type of routing protocol distance vector routing protocol, you will periodically exchange the routing control messages and from this periodic exchange of the routing control messages you will find out the path.

So this, the frequency of operations in the control plane, it is comparatively higher compared to the frequency of operations which is there in the data plane or the forwarding plane. Sometime in some book of reference the data plane is also termed as the forwarding plane.

In case of data plane if you just think about a typical router which support say 100 Gbps of data and the single packet is of size or if your say that the average packet size is 1 MB and you have say the link speed of 100 Gbps, you can think of the number of packets the data plane need to process per second. So, that is why the frequency of operations which is there in the data plane, it is significantly higher compared to the frequency of operations which is there in the control plane. And that is, that gives the interesting design choice of developing our router hardware. So, let us go to the details of that.

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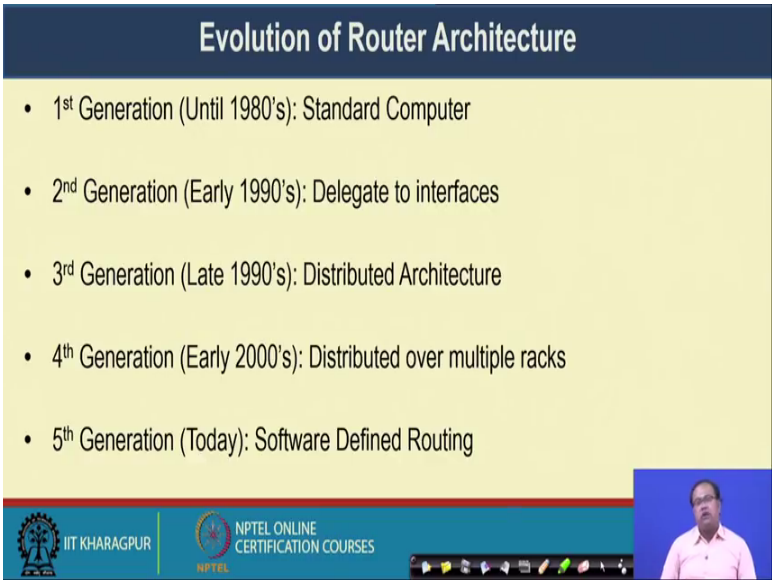

Well. So, this entire evolution of the router architecture, it came from 5 different generation starting from 1980s to today. So, the 5 generation of the router, so are just like a standard computer which we have a computer with multiple interfaces. The 2nd generation of the routers which came in early 1990s, they are delegate to interfaces. So that means, you have a router architecture where you will have multiple such interfaces at dedicated device.

The 3rd generation of the routers which came in late 1990s, we have a distributed router architecture. Then we have the 4th generation of router which came in early 2000; it is distributed over multiple racks. So, the concept of rack stack is that this entire router. So, you have say multiple interfaces say you have 32 interfaces, now say you require 120 different interfaces.

So, you take 4 different such routers and put it into different racks and have an interconnected router. And then in the 5th generation router which we are using or which will say that the next generation router or many of the large scale data centers have started using this type of routers, which are called software defined networking routers.

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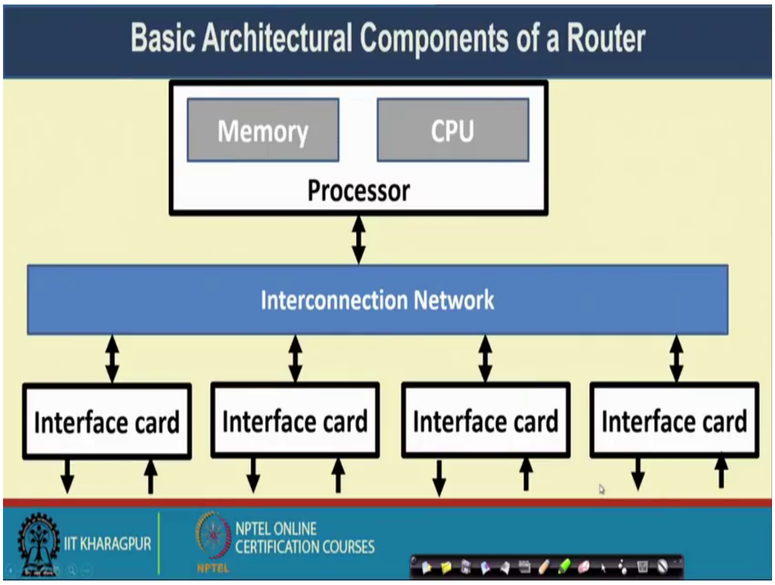

Well, so, this is the basic architectural components of a router. You have a processor, a general purpose processor which has a memory component and a CPU component. The processor is connected to multiple interface card. So, this network interface cards are the network interface card which are connected through a interconnection network inside your router hardware.

So, this every individual interface card we are kind of IO interface, the network IO interface. So, you have this RJ45 cable. So, you put this RJ45 cable in this interface card. In case of wireless, they are transmitted wirelessly. So, you have a transmitter and a receiver. So, that is the entire broad architectural component of a router.

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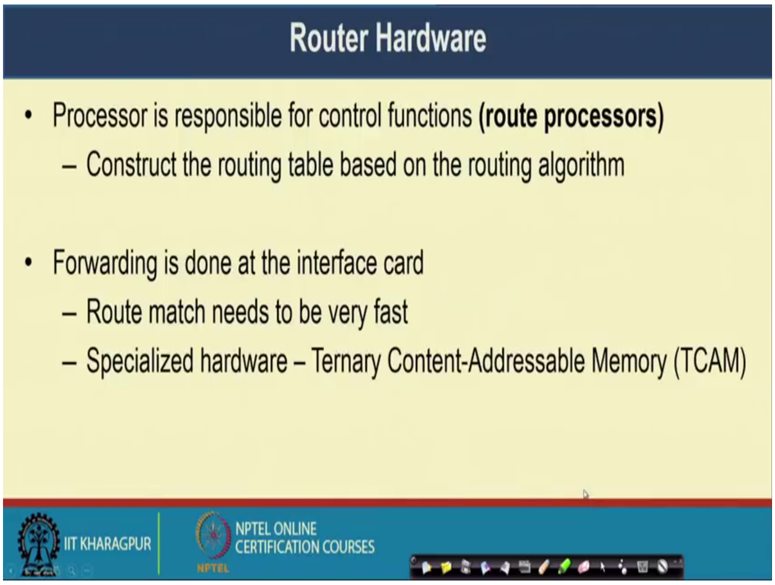

So, the router hardware the processor is responsible for the control function, we call it as a route processor. The control function means to run the routing program and then send the data packets over the network and construct the routing table.

So, the processor is basically responsible for running those programs for constructing the routing table based on the routing algorithm and the forwarding it is done at the interface curve. Because here the interesting design choices that as I mentioned earlier that your control functionalities not so frequent whereas, your data functionalities are very frequent and that is why the control functionalities we generally implement as a part of a software whereas, the data functionalities there are implemented as a part of the hardware.

So, in the network interface card this data plane functionalities that means, making a match with the routing table find out the next stop and sending it to the next stop, this entire path it is done with the help of a specialized hardware which is called Ternary Content Addressable Memory or TCAM. So, with the help of this TCAM memory we apply, we make a hardware match with the routing table for a first look up.

So, the route match need to be verifies. The example that I have given that if you have a 100 Gbps line and if you have 1 Mbps packet size, so, that is why on average you have to process a significant number of packets per second at every network interfaces.

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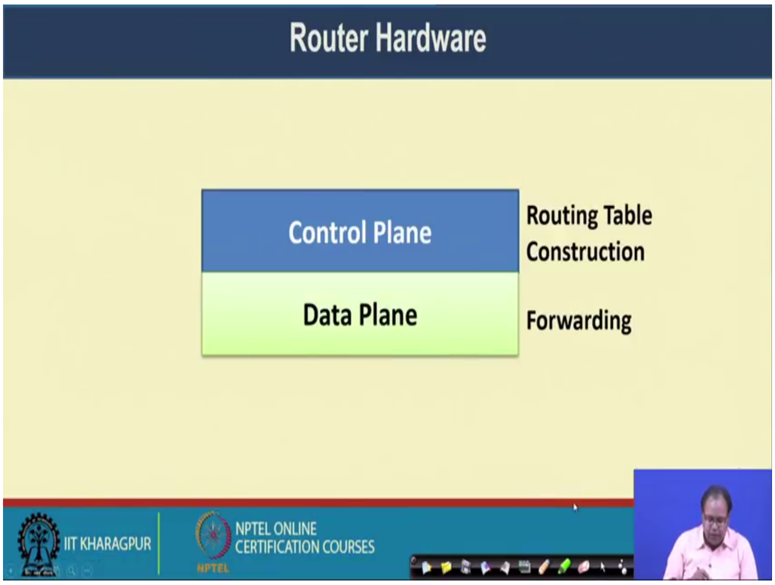

So, that way we are dividing this entire routing functionalities in the data plane and the control plane. The control plane is implemented as a part of the software which is responsible for the routing table construction and the data plane is implemented in the hardware which is responsible for implementing the forwarding engine.

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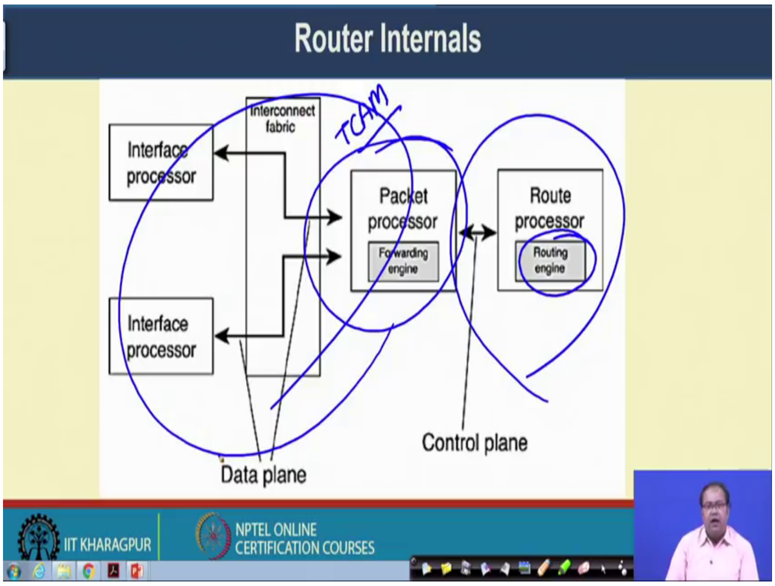

So, this is a kind of structure structural component between the mapping of the original hardware and your control plane. So, you have this interface processes which are connected to a packet processor. This packet processor contains the forwarding engine to make a match with the routing table and then find out the next stop.

So, this part is implemented in TCAM in the hardware and then you will have the route processor which is a general purpose processor which implement routing engine; that means, to finding out the path and then to finding out routing path based on the routing specific routing algorithm that you have configured in the router and in constructing the routing table. And this part constitutes your control plane and this part constitutes your data plane in the router hardware.

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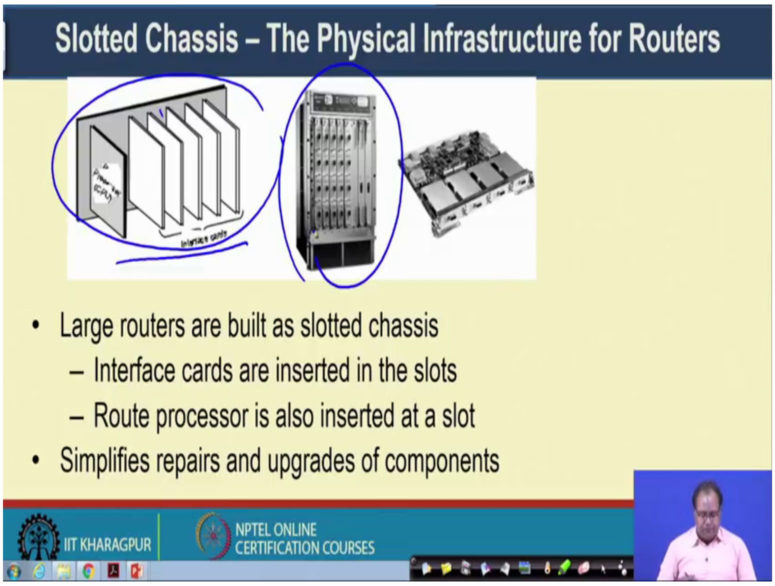

Now, if you look into the physical infrastructure of a router, we normally use something called a slotted chassis. So, this is a structure of a slotted chassis which are used to build up large routers. So, here is a structure of a chassis. So, you have this multiple chassis. So, individual interface card they are inserted inside these slots and then the route processor it is also inserted in a slot.

And then we have this entire route architecture route which looks like something like this. So, we will show a demo of this in the subsequent classes. So, this kind of a chassis slotted chassis based architecture, it simplifies the repairs and updates of components inside a router.

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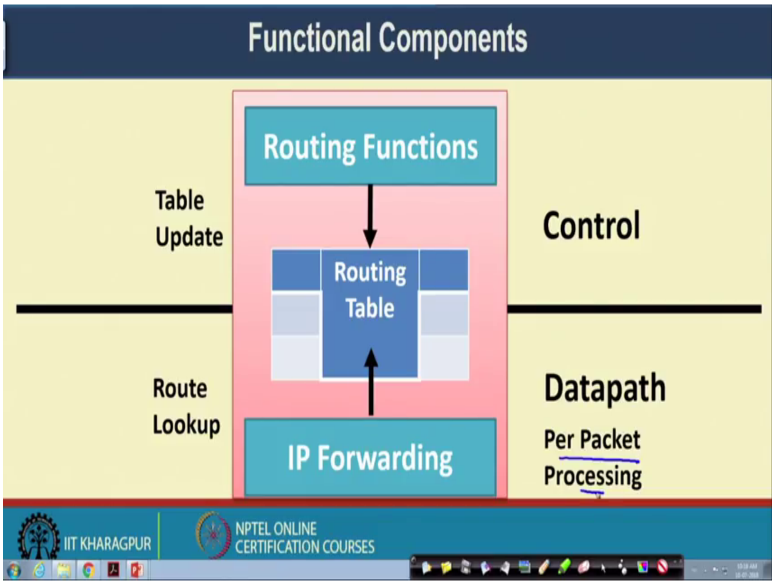

Now, let us look into the functional components of a router from the perspective of the control and the data path. You have the routing function and in the data path you have the IP forwarding as we have mentioned.

And in between you have the routing table. So, this routing functionalities they apply the routing protocol, different kind of routing protocol based on your configuration, it may be OSPF or RIP kind of routing protocol, routing information protocol or open slotted passed first, which are kind of distance vector and a link state routing protocol. So, with the along with this distance vector or link state routing protocol you can also have border gateway protocol.

So, these routing protocols they execute periodically and construct the routing table. Now this forwarding engine it makes our outlook upon this routing table and make up our packet processing of the routing informations. So, the idea is something like this whenever you are receiving a packet you look into the IP header, from the IP header you extract the destination IP field after extracting the destination IP field then you make a match with the routing table find out the next of interface and forward the packet to that next of interface. So, that is the entire process which is being executed in the data path.

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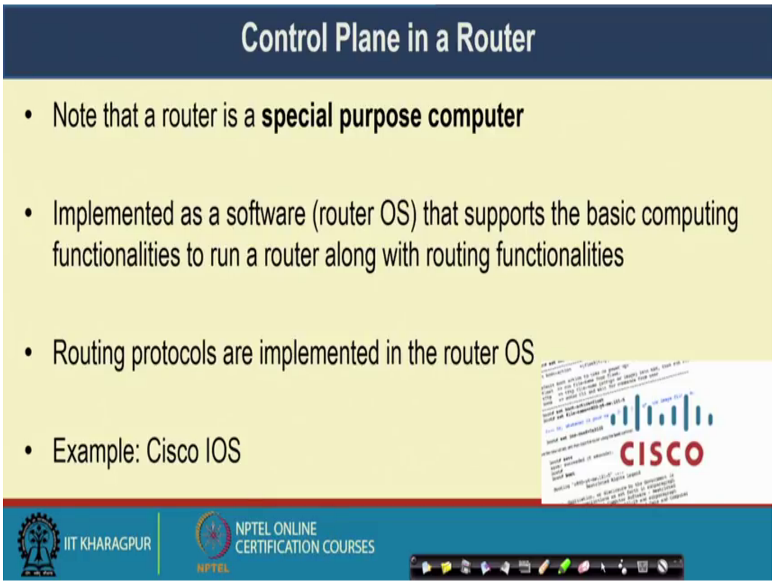

Now, the control plane in a router it is a special purpose computer which has the routing functionalities. As I have mentioned it is implemented as a software that software we call as a router operating system router OS that supports the basic computing functionalities to run a router along with the routing functionalities. Now, this routing protocols, they are implemented inside a router OS. An example of our outer base is the Cisco IOS, Cisco internet operating system which implements different kind of routing protocol as a part of its operating system.

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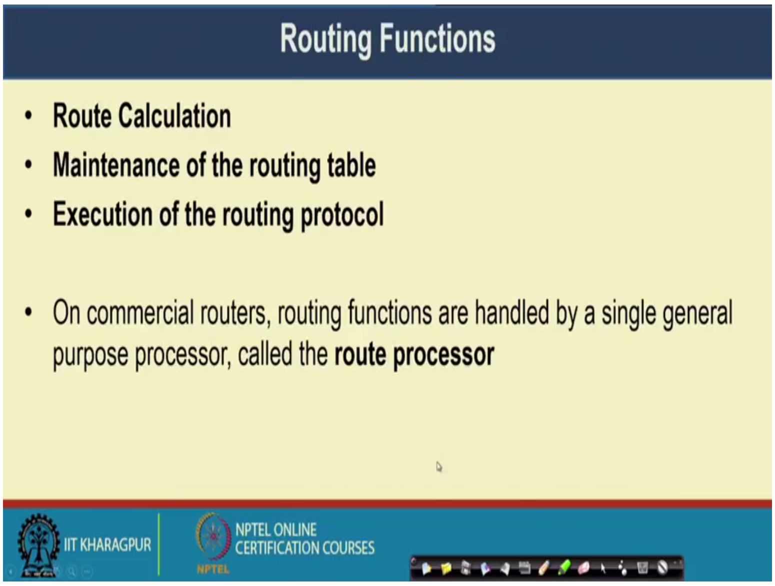

Now, the routing functions are basically there are 3 functionalities that you need to execute inside the control plane of a router, the route calculation based on a routing protocol, the maintenance of the routing table and the execution of the routing protocol. Now, in commercial routers, these routing functions are handled by a single general purpose processor which we call as the route processor that I have mentioned earlier.

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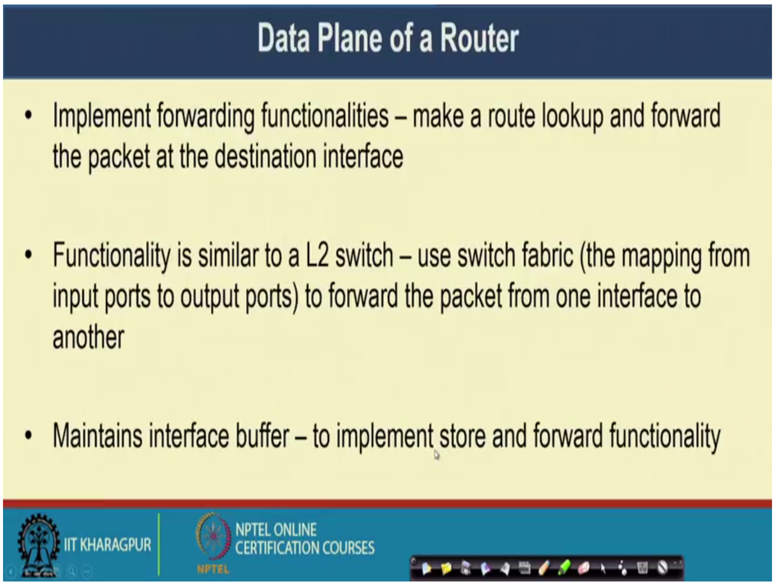

Now, the data plane of a router that is the interesting part, it implement the forwarding functionalities. So, it make outlook up and forward the packet to the destination interface. So, this functionality is similar to a layer 2 switch. So, you can use the switch fabric. So, a switch fabric means it is a mapping from input ports to output ports; that means, if a packet is a make input to a particular port in which output port it needs to be forwarded to; so, a switch fabric looks something like this.

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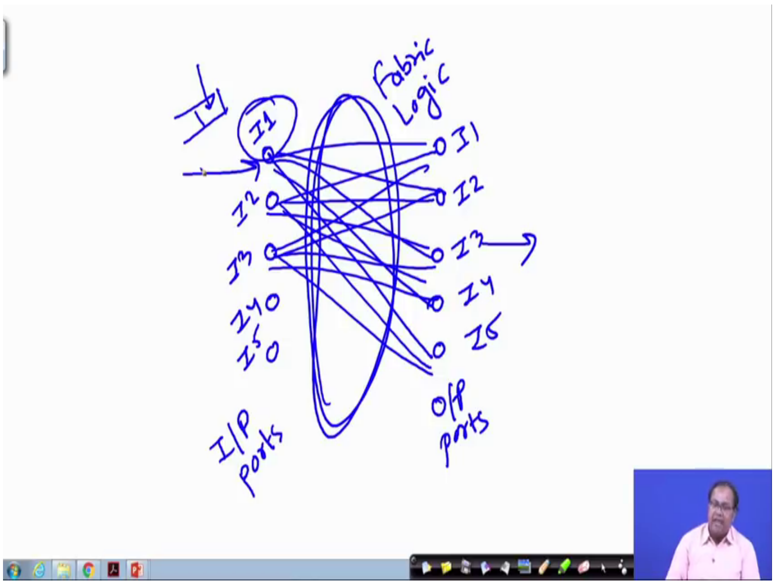

So, a switch fabric means you have a set of input ports and from this input ports you have you have a set of output ports. So, these are input ports and these are your output ports. So, interestingly in router this input ports and output ports are same. So, the input ports and output ports are basically the interfaces. So, this is I am naming the interfaces according this; I 1 I 2 I 3 I 4 I 5, any of the interface can work as an input port as well as an output port; similarly, I 1 I 2 I 3 I 4 I 5. So, a switch fabric it is a hardware connection that make a connection from one port to all other output ports.

So, that way inside this fabric logic, so, this is this context are fabric logic. So, this fabric logic a set of logic gates which actually forward the information which is fed to a one input port to another output port. So, that is the functionality of the logic gates which are there inside the switch fabrics. So, that way in a router whenever a packet comes in an input port from the destination address field, you make a route look up inside the routing table and then decide which is your output port. Say for example, for a packet at input for I 1, if decide based on the routing table that the output port should be I 4 then this fabric logic will copy the data from this input port to the output prototype ports ok.

So, it maintains also maintains time interface buffer to implement the store and forward functionality. So, whenever you are getting the packets you are getting the packets 1 after another. So, it every interface you should have a buffer packet should be temporarily inserted inside the buffer then one of the another they will be transmitted over the link by the layer 2 at the data link layer.

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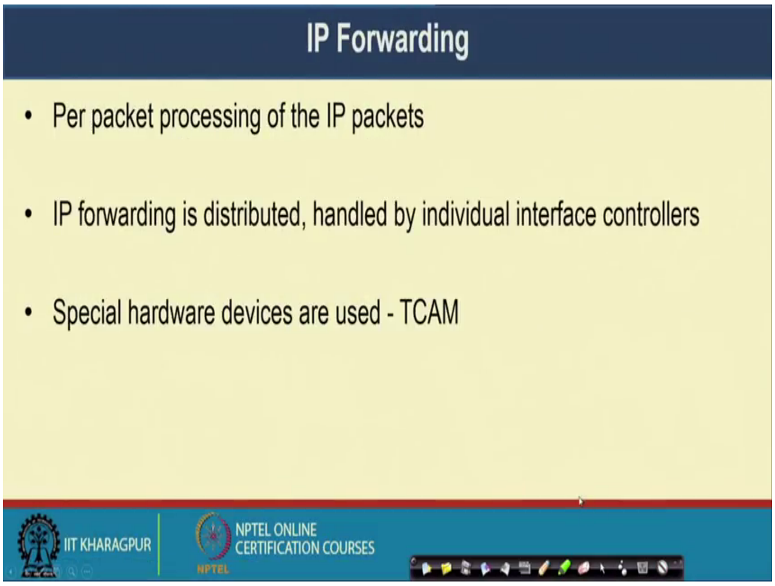

Now, in IP forwarding we need to do a power packet processing of title packets. Now, IP forwarding is distributed. Distributed in the sense like, it is handled by individual interface controller. So, this network interface they are kind of micro controller. So, you have a interface controller there. The interface controller handles the packet forwarding which are coming to a single interface. So, for this packet forwarding we use the special hardware devices which are the TCAM ternary content addressable memory which makes a 1st mapping, 1st match between a table and the corresponding input.

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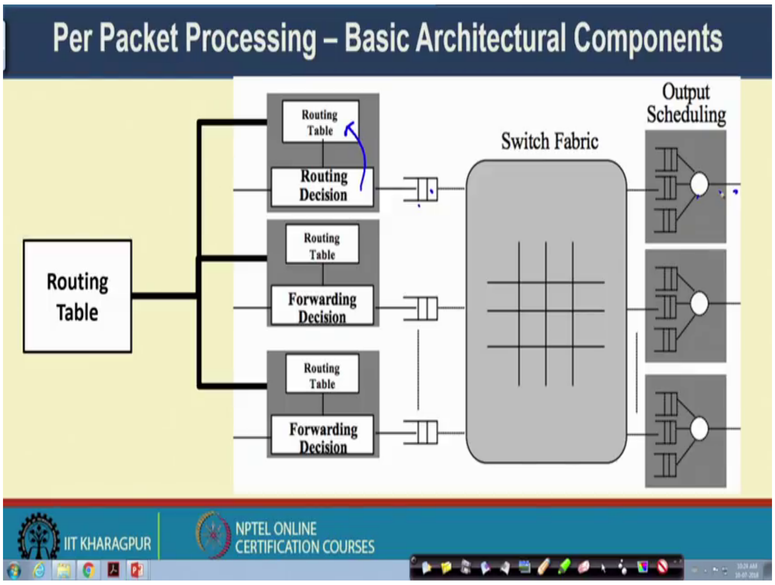

So, the per packet processing the basic architectural components are something like that you have a routing table, a copy of the routing table is put in every individual routers. So, whenever you are putting a copy of the routing table at every individual routers, whenever a packet comes this interface controller it makes a routing decision by looking into this local routing table. So, this local routing table has a name it is called a forwarding information base which will come after a couple of minutes. So, it makes a routing decision, put the packet in a queue and then you have this switch fabric the fabric logic which make a mapping from this input queue to the output queue.

So, this output queue is connected to the output interface through which the packet is forwarded. Now, as I mentioned that every router interface can work as an input queue as well as an output queue.

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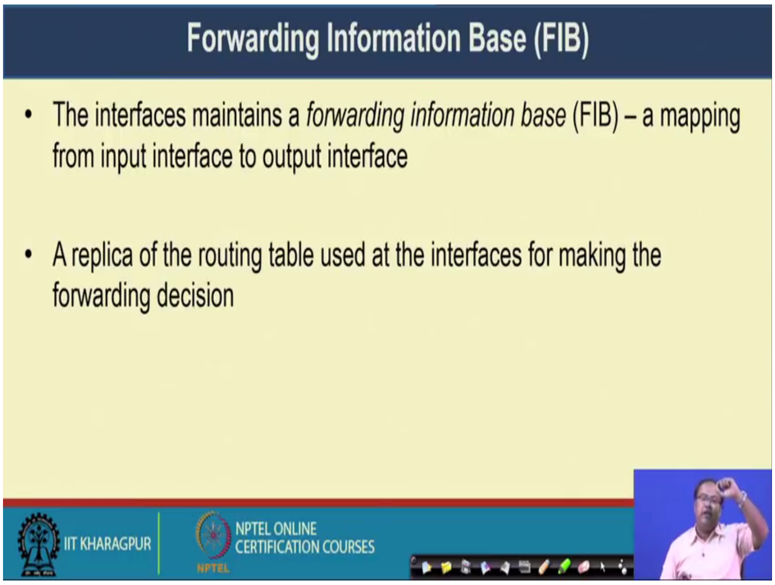

So, the interfaces they maintains a forwarding information base which is the local routing table. This forwarding information base is a mapping from the input interface to the output interface.

So, the forwarding information base is nothing but a replica of the routing table used at the individual interfaces for making the forwarding decision. So, a copy of the routing table it is put in every individual interfaces in the form of a forwarding information base.

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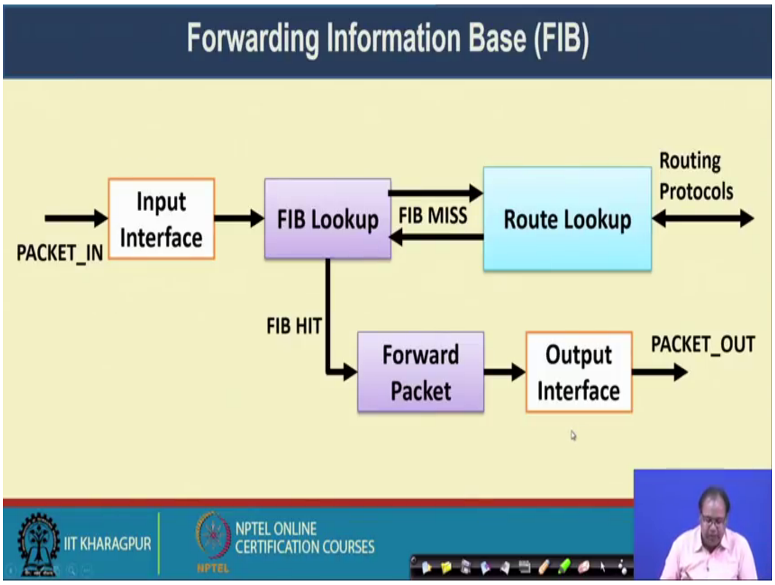

So, this is a the idea that whenever you have a packet in event; a packet in event means a packet is input to the system it is put into the input interface. In the input interface you look into the forwarding information base your local cache of the routing table which is implemented inside the hardware. After looking into this local cache, if there is a here; that means, the information is there in your FIB.

So, you forward the packet, put the packet in the output interface and execute a packet out event; that means, output the packet to the link. Otherwise, if there is a FIB means; that means, the information is not there in the forwarding information base. You look into the routing table, make a route lookup. The route lookup procedure will interact with the routing protocol, get the routing information and put it in the FIB.

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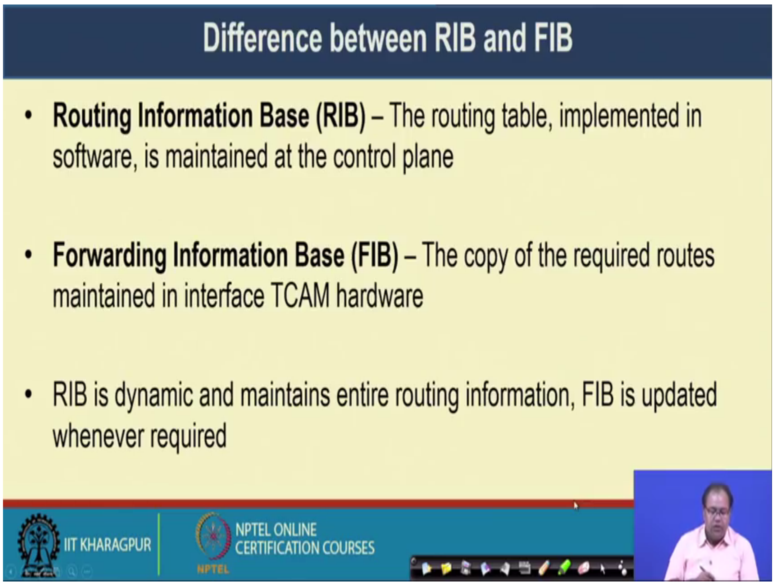

So, the difference between RIB and FIB is that the routing information base is the original software routing table which is a implemented in the software and maintained at the control plane. And forwarding information base is the copy of the required routes maintained at the interface of the TCAM hardware. Now, this RIB it is dynamic and maintains the entire routing information, whereas, FIB updated whenever required.

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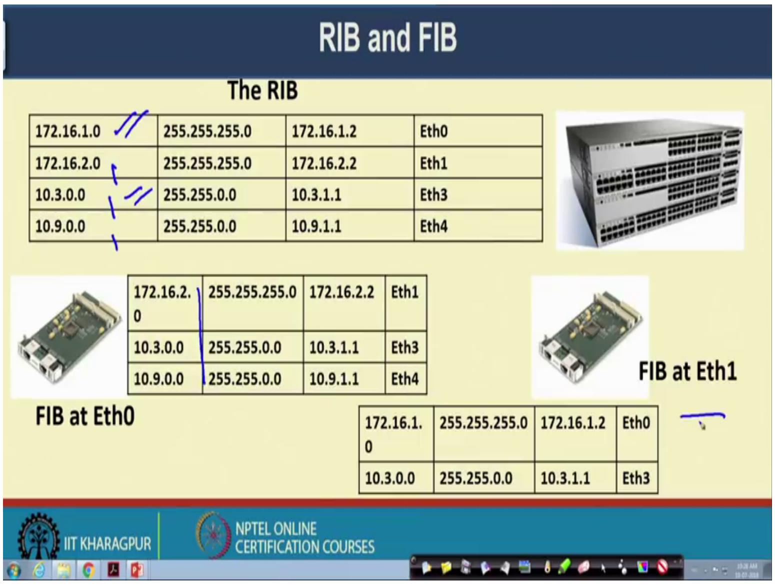

So, here is an example. So, in the route controller you have this entire RIB. Now, in individual interfaces like Eth0 and Eth1, you have a copy of this RIB. So, here in this Eth0 you have the information about these 3 entries; these 3 entries means, this entry, this entry and this entry, whereas here, you have the information about this entry and this entry at Eth 1. So, that way a part of the routing table is copied to the FIB, forwarding interface information based at individual network interface whenever required.

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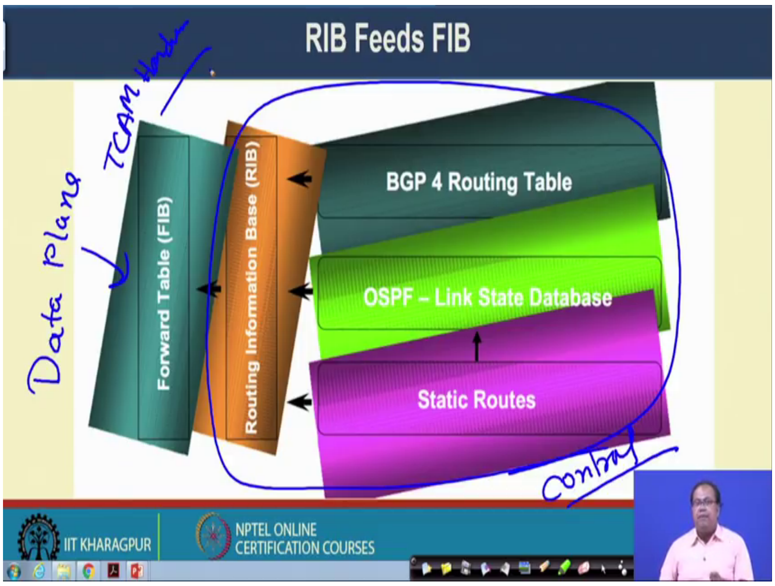

Now, this RIB feeds the FIB. So, that means, you have this multiple routings algorithm, every routing algorithm may have their own routing table. So, you have the BGP routing table, you have the OSPF that contains the link state database, you have the static routes which network program are inputs manually. So, all this information they feed the routing information base and from the routing information base whenever require the information is copied to that TCAM hardware in the forwarding information base.

So, by interesting design choice in a router is that this entire control plane functionalities; that means, this routing protocol along with the routing information based that is your control functionalities that is implemented as a part of the software. Whereas, in the data plane, you have the routing information in terms of forwarding table or the forwarding information base which is implemented inside the TCAM hardware to make a fast lookup of the information. So, this TCAM hardware, so, I am not going to the detail logic design of the TCAM hardware.

So, if you are interested you can look into the design of the TCAM hardware. It is a special type of hardware which makes first lookup of an information inside the table. So, again repeating this entire procedure that whenever you are receiving a packet first you extract the IP header, from the IP header you extract the destination IP address then you use the TCAM hardware to make a match with the forwarding information base.

If the information is already there you then use the switch fabric to copy the packet from the input interface to the output interface. If the information is not there in the FIB then you need to make software control at the routing information base to get the information from the routing information base and update the FIB.

So, that way this entire routing procedure is implemented inside a router. So, that is a brief introduction about the router functionalities. In the next class, we will look into a demonstration of a practical router, of an ATPG router and we look into the different component of it in a little details.

Thank you all for attending this class.