Broadband Networks

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Lecture - 26

Optical Network &MPLS

So, as you were discussing in the previous lectures, next generation optical networks and the role of MPLS in next generation optical networks. As we have already discussed here that we have an IP networks and an ATM which runs over a SONET SDH and we have an optical or DWDM networks a physical layer.

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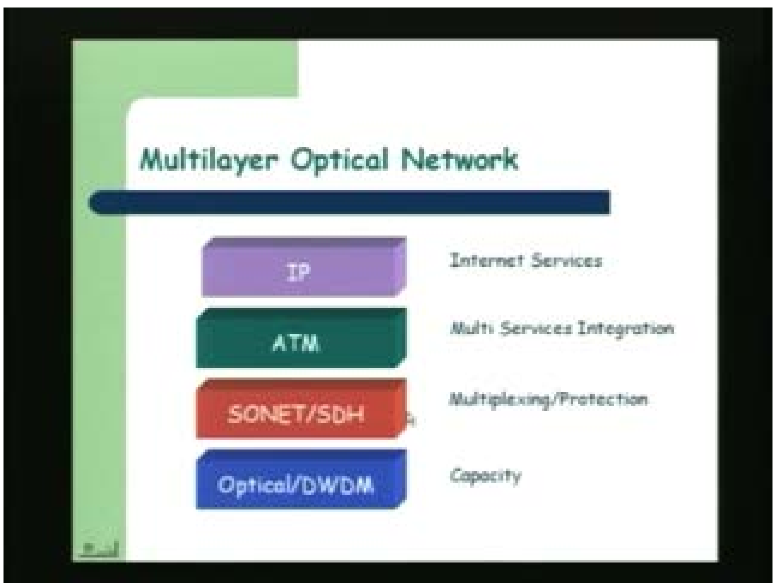

So, as you can see from this slide that essentially the job of the SONET SDH is to provide multiplexing and also to provide protection and the restoration capability at the fiber level. The ATM provides most of the transport functionalities and integration of multiple services. So, this is the job of the ATM and of course, the IP is run over all these networks to provide internet services.

Now, at the physical layer you could have optical or DWDM networks to increase the capacity. So, these are basically fiber based networks. If you do not meet high capacity, then you could just have IP ATM SONET SDH networks.

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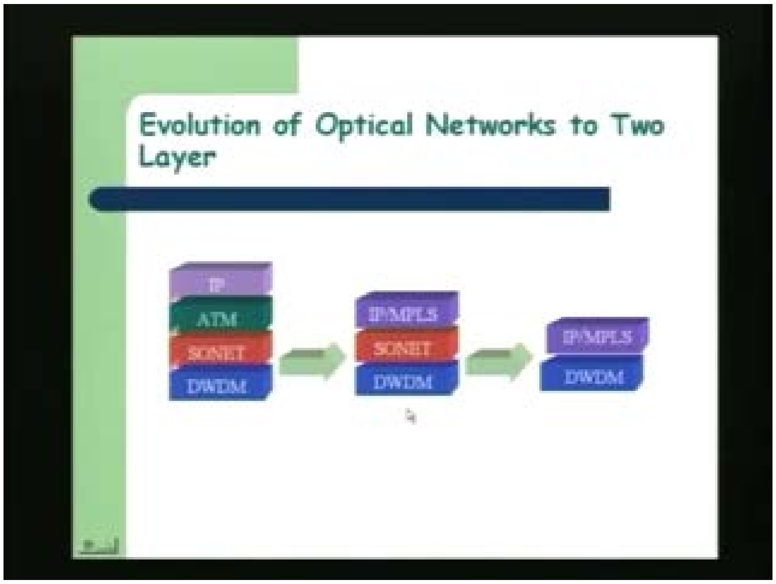

Now, as we already discussed that the evolution of optical network is taking place from this 4 layer networks to a 2 layer networks and as we can see the transition that this ATM layer is completely replaced by IP MPLS and latter on the SONET or SDH layer also may be replaced. So, if you can see here, why ATM network was used? The ATM network was primarily used to provide the traffic engineering capabilities in the core networks and for providing integration of multiple services.

We have already discussed that the traffic engineering capabilities and integration of multiple services, the service multiplexing can be accomplished by combination of IP and MPLS network. So really speaking, in the next generation networks, all the job of ATM can be done today by IP and MPLS and whenever we need the quality of service guarantees, we can incorporate those quality of service guarantees in the IPQS model as well and that IPQS model can be extended to an MPLS base network that we have already discussed.

Now, as we are evolving, as the optical networks are evolving … next generation networks; we can see that even the SDH layer that is even the SONET layer can be replaced by the DWDM networks. You no longer require the SDH or SONET layer, as we go to a higher capacity fiber optic network; then you just need the DWDM at a physical layer.

Now, at that point if you do not have the SONET layer, if you are just having a dark fiber bit DWDM used to light up the fiber, then if the services integration transport all services need to be provided by a combination of IP MPLS network; then it is very clear that protection and the restoration capabilities will also have to be provided by MPLS network or by using the capabilities of the IP restorations.

So, that is where we were looking at really that how MPLS, how the traffic engineering capabilities of the MPLS can be used to provide protection and restoration at the optical networks. So, we will we have already seen that when the IP network is run over an optical network like DWDM base networks directly IP over DWDM; we can either have overlay model or we can have a peer to peer model. In the overlay model, the IP over optical networks works in the similar fashion as we have seen IP over ATM overlay model.

In an integrated peer to peer network, there are no separate control planes for IP routing and optical routing. As a matter of fact, the IP routing is integrated with the optical routing and a single control plane exists. Now, let us first look at the overlay model. We have been looking at a sort of the overlay model.

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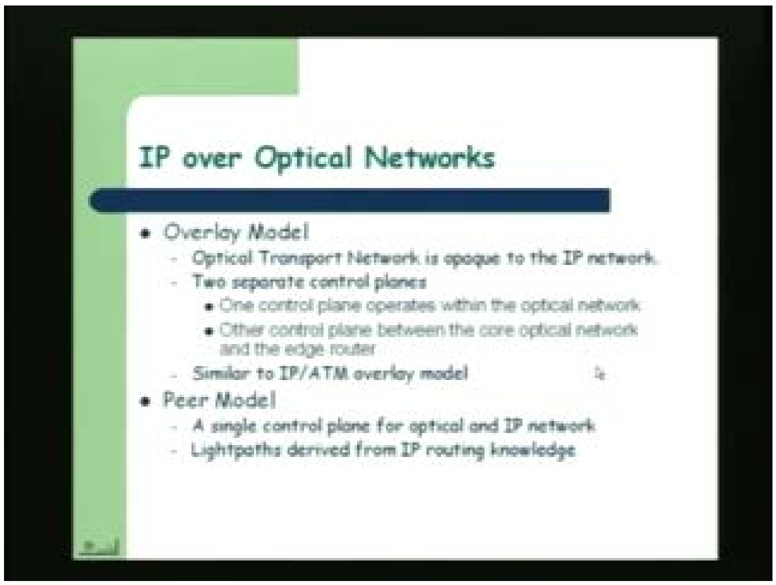

So thus, we have already seen that in overlay model there are 2 separate control planes and in peer model, there is only a single control plane.

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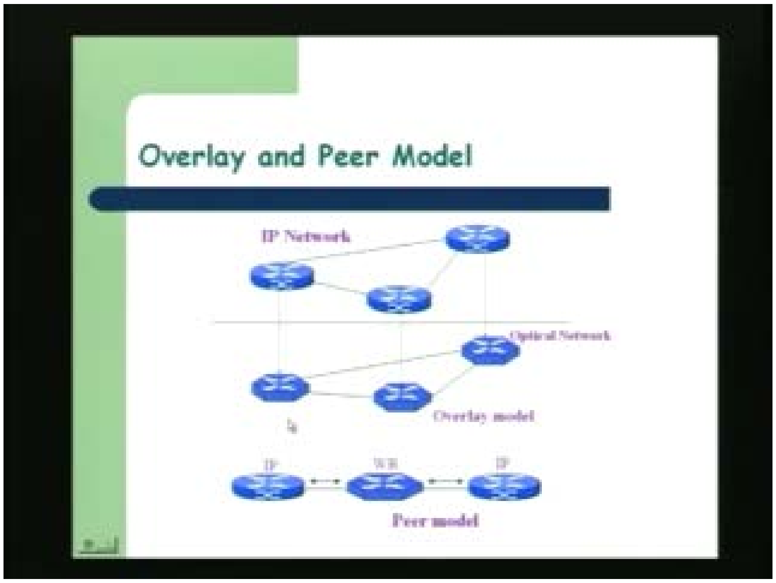

So, this is like our overlay model. We have these are optical routers which are situated at the edge of the networks and in the core of the network, we have these wavelength routers and what is done really is that this optical network, this IP network is overlaid over this optical network which comprises of the wavelength routers.

In the peer to peer model, as you can see that now what happens in the overlay model? There are 2 separate routing protocols that are in place; one is the IP routing, another one is the optical routing. Now, so what happens in the IP routing? The routes are determined based on the IP addresses by the IP routing protocol and in the optical networks, this light path either may have been statically provision or they may be dynamically determined.

In either of these cases, what happens is that this route determine based on IP addresses is then overlaid over the light torch which have been determined by using some optical routing protocol. But in the peer to peer model, the optical route themselves are determined by using intelligence from the IP routing protocol. So, here as we have see in the peer to peer model, the wavelength routers also participate in the IP routing.

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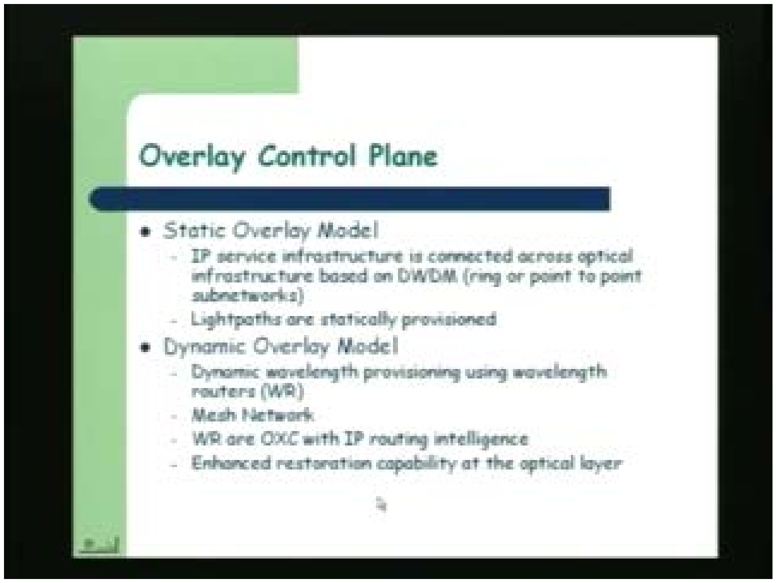

So, let us look at the control plane. As I was just discussing in overlay model, you can either have a static overlay model or you can have a dynamic overlay model. So, dynamic overlay model will do the wavelength provisioning dynamically using basically wavelength routers and these wavelength routers are nothing but optical cross connects with some routing intelligence. On other hand, in the static overlay model, you just have a plane optical cross connects and then your light path, you can provision it statically and then fix it. The dynamic overlay model allows you to do the provisioning of the wavelength dynamically.

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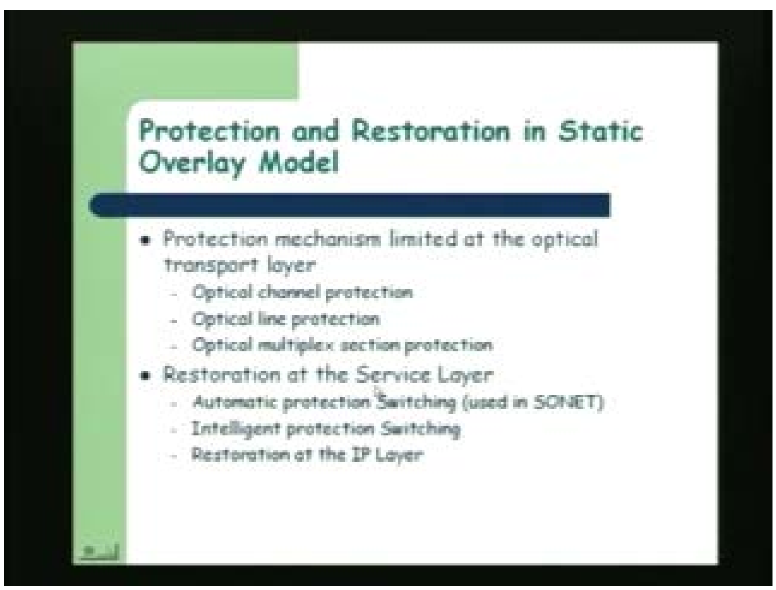

So, as you are looking at how protection and the restoration will be done in this overlay model, both in the static overlay model as well as in the dynamic overlay model. So, the protection mechanism is actually limited at the optical transport layer and if it is the transport layer is based on the SDH, then you are actually using the protection and the restoration capabilities of the SONET SDH.

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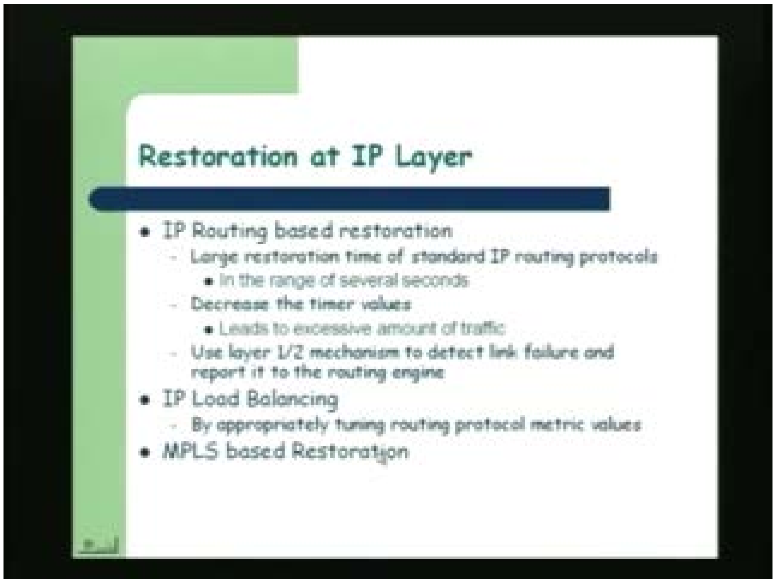

You can also have a restoration at the IP layer also but as we have discussed, there are problems if by using the techniques of restoration at the IP layer essentially because of the large restoration times which are there with the standard IP routing protocol and which can range of the order of several seconds. We can of course get around this problem by decreasing the timer values. But then it will lead to an excessive amount of traffic.

Now therefore, if we have to really do restoration or protection at IP layer, we may have to use some of the capabilities which are provided by the MPLS traffic engineering and we will see how MPLS traffic engineering based mechanisms can provide protection and restorations.

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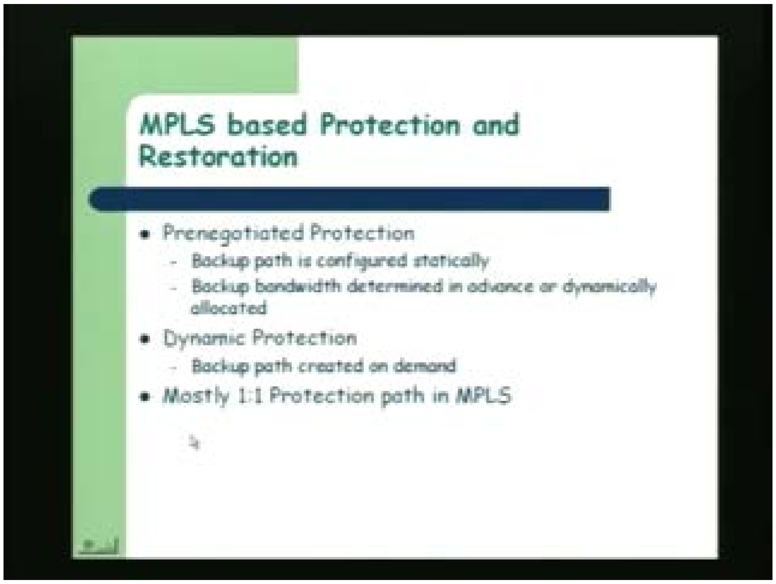

So, in the MPLS based protection and the restoration, what you can do is that in MPLS the backup path is created there. So, there is a primary label switch path to forward the traffic from ingress to ingress. So, there is a primary backup path and then there is a primary label switch path and then there is a secondary label switch path which also exists. So, whenever primary backup path fails, the traffic which was flowing on the primary backup path then gets automatically routed on the secondary labels switch path. So as a result, a protection can be provided.

When the secondary backup path is not a required by this traffic which is right now following the primary backup path, then this secondary LSP can also be used to forward low priority traffic. It may be best effort traffic or some other traffic; it can forward it. Whenever the primary label switch path fails, then that high priority traffic which was going on to the primary LSP path can then preempt this low priority traffic which is going on the secondary LSP path and then it can start getting forwarded on the secondary LSP path.

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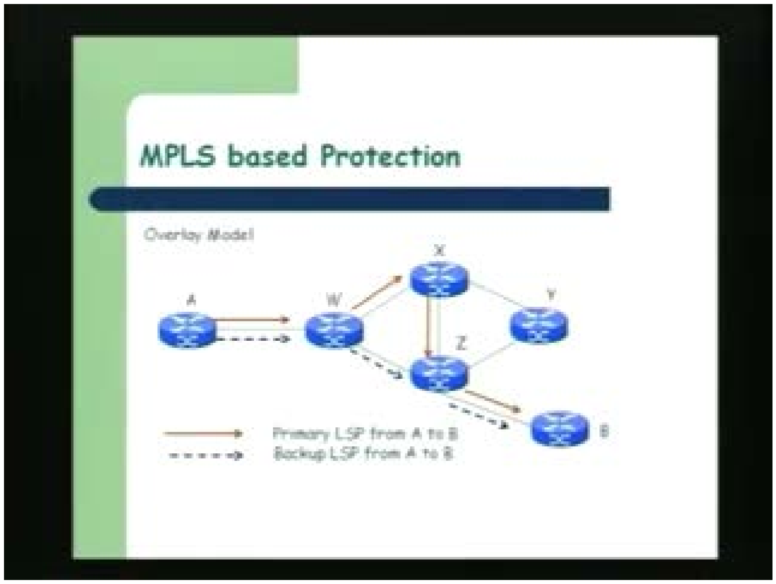

So, this is really a scenario which you can see here is that there is a primary label switch path shown by this red line from A to B network which is passing through these routers A, W, X, Z and then there is a secondary label switch path shown here which is going from A, W, Z to B. Now, let us say if this link fails or if this link brakes down, then the traffic cannot go on this link and whenever it is detected by X N and the W comes that this link has broken down. Then it can start forwarding the packet on the secondary backup path.

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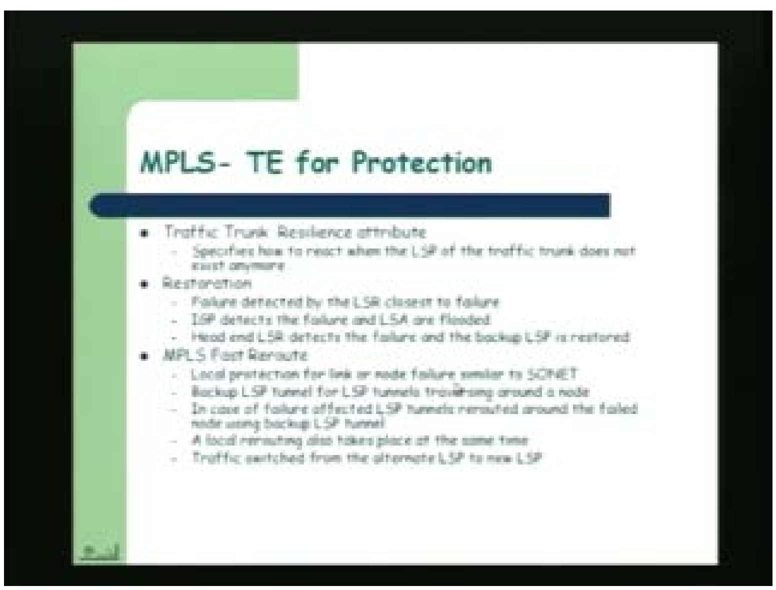

Typically therefore, this will have a better restoration time than at the IP layer. So, MPLS traffic engineering has been standardized MPLS TE for the protection purposes. That has certain traffic trunk resilience attributes; so whenever you setup a traffic engineered path, you need to associate before you setup the traffic engineered path. As a part of the signaling protocol, as a part of the signaling used for MPLS TE; you need to specify what are the traffic trunk resilience attributes and this specifies how to react when the label switch path of the traffic trunk does not exist anymore.

So, the traffic trunk resilience attribute will actually specify how they react. So, this should be specified as a part of the signaling protocol for setting up the traffic engineered paths. Then the restoration; so typically, the manner in which restoration is done is the failure is detected by the label switch router which is closest to the failure and then the routing protocol detects the failures and the label and the LSA, the labels switch advertisement are flooded and the head end LSR then detects the failure and backup LSP is restored.

So, this is how it, I was just discussing that if this link fails down, then the X detects this failure. X will send all LSA's to Y and W. So, this head end LSR W comes to know that this link has broken down and it will immediately restore the backup LSP which was already in place from A, W, Z to B. There could also be a fast reroute mechanism and this acts like a local protection for a link or note failure, very similar to a SONET or SDH network

So, now what happens in the fast reroute mechanism that there is a backup LSP tunnels for the LSP tunnels which are traversing around a node and incase of failure, the effected LSP tunnels are rerouted around the failed node using the backup LSP tunnels. So, it is like this that if this node this node brakes down, then there may be a backup LSP around this node itself. So, then all the packets, they cannot be forwarded on this link. Then they may get forwarded from X to Y and then from Y to Z and then come here. So, there may be a fast reroute done around the node X which deducted the failure.

Obviously here, the restoration time is much less. So, that is the reason it is called fast reroute. But the paths that are chosen may be suboptimal. So, what is however this is only or temporary phenomenon. So, what happens is that a local rerouting then also takes place at the same time and then when a new LSP is setup, the traffic is then switched from this alternate LSP that is the fast reroute LSP to this newly setup LSP it is again rerouted.

So, that the sub optimality in terms of forwarding the traffic is only there for a fraction of second. So, this - the MPLS fast reroute capabilities, actually gives you a faster restoration time compared to a backup LSP or the IP restorations. So, in summary what happens is that what we are saying is that in the core of the networks, we have this optical based network which is based on this wavelength router and over which we are overlaying the IP networks. But when we are overlaying the IP networks, we are also running MPLS primarily to provide traffic engineering capabilities in the networks.

So, as a part of MPLS traffic engineering signaling protocols, we will not only setup the primary LSP path but we will also setup the secondary LSP paths which may be around each node incase of link failure or detection or completely a secondary LSP path which may be woken up whenever the primary LSP path fails. So, these are the protections and the restoration mechanism which are available in terms of MPLS traffic engineering capabilities.

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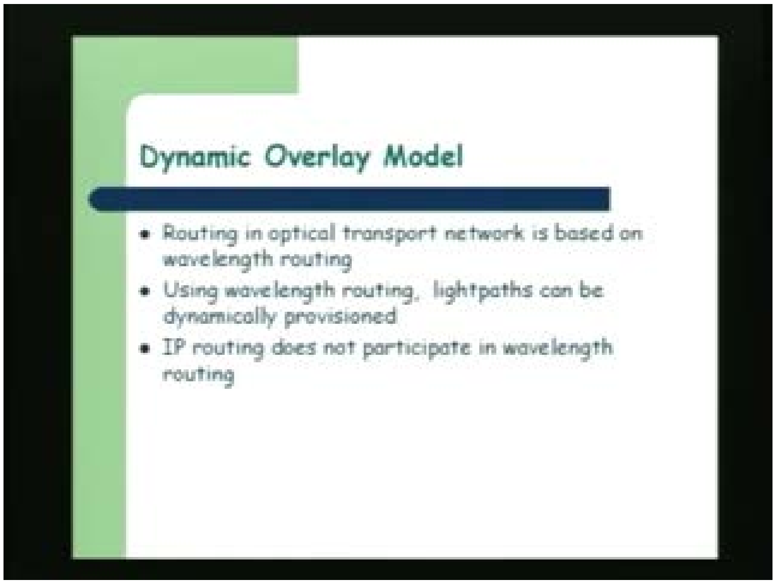

In dynamics, so this in the static overlay model, as we have already discussed again; in the static overlay model, the light paths have been statically provisioned and they are dumped optical cross connects which have been used in the core of the networks. As opposed to that in dynamic overlay model, we have this wavelength routers which are basically optical cross connect with routing intelligence and they can do dynamic wavelength provisioning.

So, the routing in optical transport networks is based on wavelength routings and by using wavelength routing, light paths can be dynamically provisioned. However, the IP routing does not participate in wavelength routing. So since, it is an overlay model, the IP routing intelligence is not used for wavelength routing. So, there is a separate control plane for IP routing, of course and there is a separate control plane for wavelength routing.

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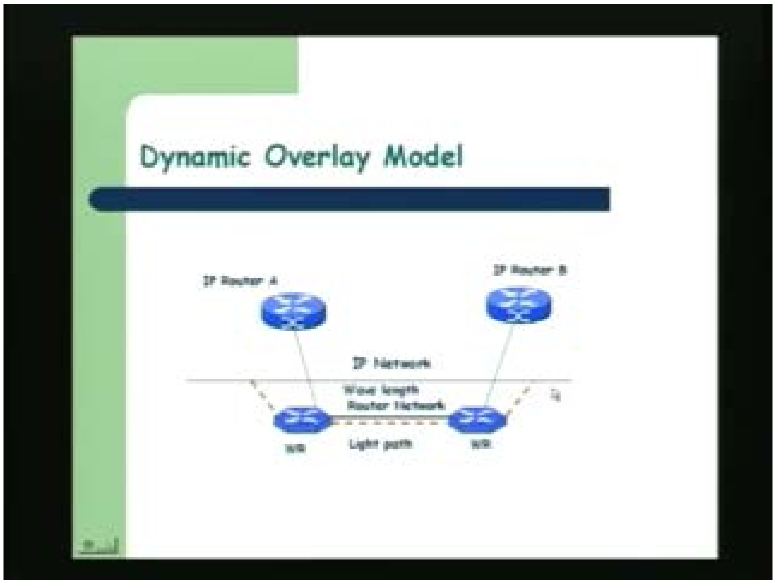

So, this is how it works here; there is an IP router A and there is an IP router B and these are wavelength routers. So, a light path has been setup using an optical routing intelligence and the IP routers however determine their routes based on the IP addresses only.

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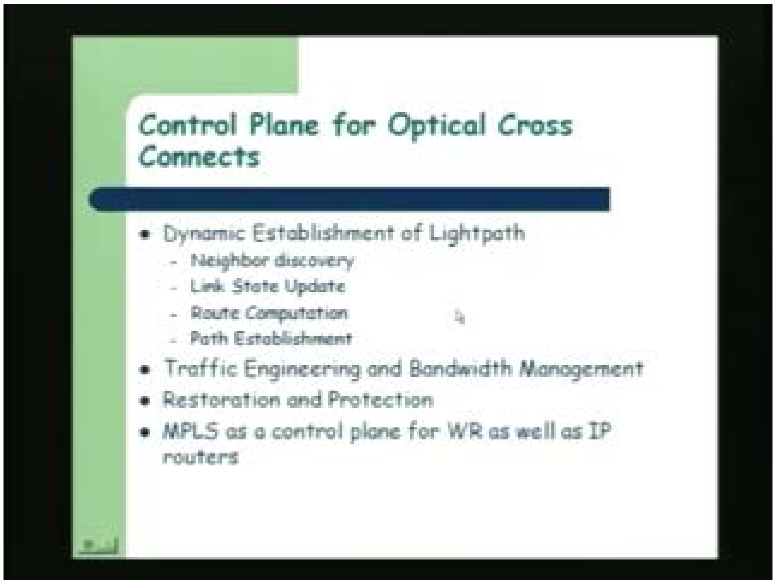

Now, there is a control plane for optical cross connects. Now, this is like the control plane for wavelength routers. You require to have a now since in this case a light paths are not statically provisioned, you required to have a dynamic establishment of light paths which includes features like neighbor discovery, links state update, route computations and the path establishment. So, these are the features which are required for dynamically establishing the optical path.

Then these optical paths, you can also do the traffic engineering on this optical paths and you can also provisioned the bandwidth of this optical paths. You of course, need to have a restoration and protection capabilities in the optical path. Then the question really is that what kind of control plane we can have for this optical cross connects.

Now again, I want to emphasize here that the control plane for the IP routing, IP routers is there is a routing plane which is the intelligence used in determining the routes based on IP address. We had seen that MPLS has a significant utility as a control plane in the IP routers itself to provide traffic engineering.

Now, here is say a wavelength router. In wavelength routers, we are saying that we will do this dynamic wavelength provisioning. But we need a control plane for the wavelength routers also. Now, we need a control plane which should be able to do dynamic wavelength provisioning, which should able to do traffic engineering, which should able to do bandwidth provisioning, which should be able to do the optical routing, which should be able to determine the neighboring nodes and so on.

So, the question really is that what is the best control plane for the optical cross connect. It turns out that MPLS with certain modifications can actually act as a good control plane even for the optical cross connects. So, that leads to an integrated IP optical peer model that is what you know we were discussing. So, instead of overlay model if I am using the MPLS to be a control plane for optical cross connects; then I can also use to determine this traffic engineering path, I can also use a knowledge of the IP routing and if the edge of the networks I am having this IP routers also with the MPLS as the as the control plane, then I am having an integrated intelligence next generation optical network which is based on this peer to peer model. Except that when we are using MPLS as a control plane for the optical cross connect, we need to make certain changes in the MPLS protocol to take care of the fact that it is now have to manipulate this optical cross connects and not the IP packets.

So, that leads to the development of what we call as the generalized multiprotocol labels switching protocol or the GMPLS. Now, let us look at the integrated IP optical peer model. So, in peer model, only one control plane as we are discussing - spans and administrative domain.

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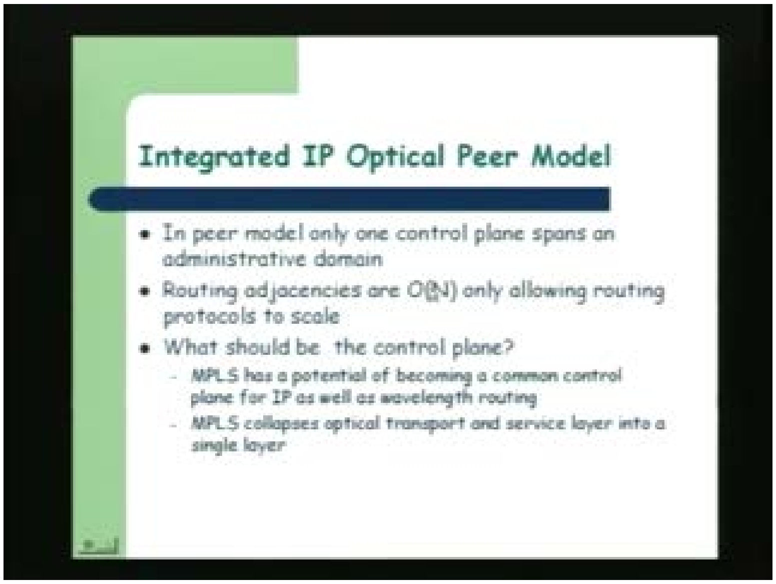

And, the routing adjacencies are of the order N, so allowing routing protocols to scale. As you can as you have seen that in the overlay model both, when we are having IP over ATM and as well as IP over optical; the routing adjacencies were really of order N square and therefore the routing protocols scaling. And, what should be the control plane?

So, as have we had just discussed, MPLS has a great potential of becoming a common control plane for IP as well as wavelength routing because what happens really is that MPLS will then collapse the optical transport as well as the service layer into one single layer and that is like a uniform integrated control plane.

So, what we are essentially saying is that not only we have integrated the wavelength based routing with IP routing in providing a peer to peer model but in the form of MPLS, we have also got a unified control plane covering from IP routers to the wavelength routers and this really leads to a great powerful frame work for the next generation core networks. So, this is how it looks like.

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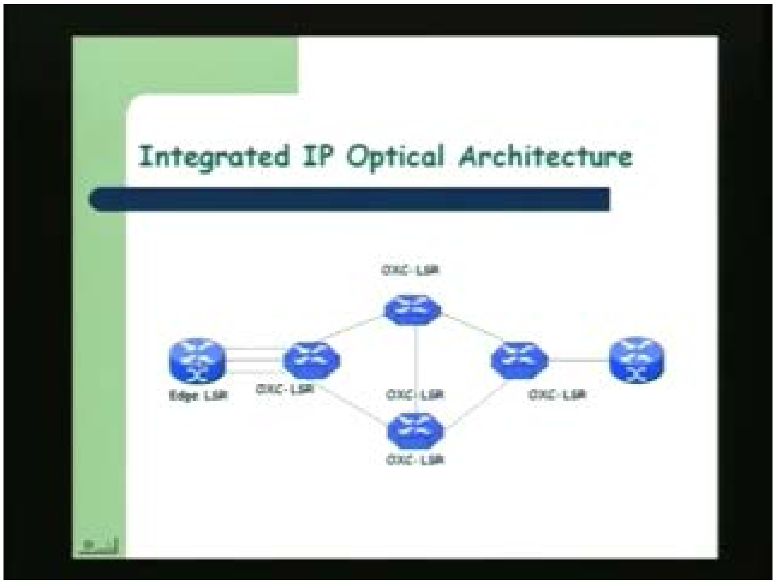

You can see, this is an edge LSR, a labels switch router which is basically an IP router with MPLS control plane but these are optical cross connects label switch routers in the core of the networks which are using MPLS as the control plane and these are the light paths are actually provisioned by using the traffic engineering capabilities of the MPLS network. So, this is like an integrated IP optical architectures which is truly a next generation optical networks.

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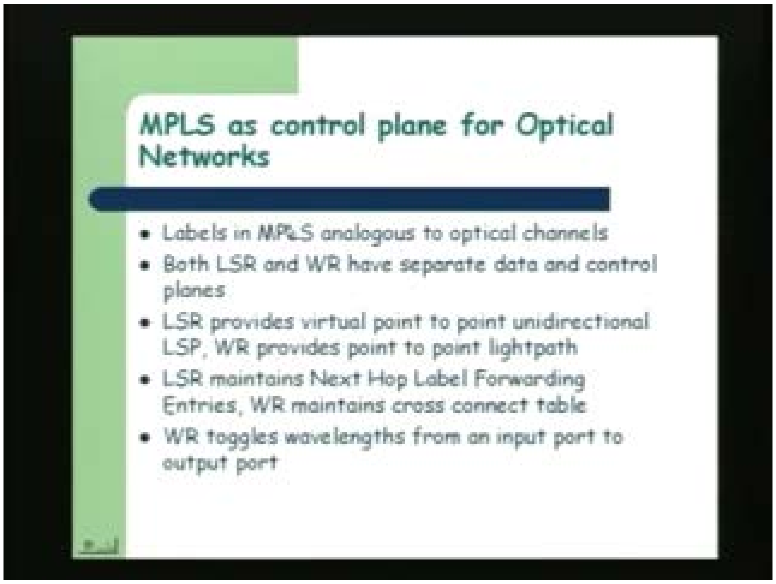

So, let us look at what changes of features we have to add in order to make MPLS as a control plane for the next generation optical networks. Now again, when we have to make these changes in the MPLS to act as a control plane for the optical cross connects; we have to take care of the fact that in the core of networks which is based on optical cross connect, MPLS is basically used to configure and setup the wavelengths. When this core network was based purely on the IP base networks, then the MPLS was actually used to setup the traffic engineering path but operate on the IP packets.

Now, here it will setup the wavelength and it will configure the wavelength provisioning. So, therefore you know it has to act on the wavelength rather than on the labels or IP headers. So, labels here in MPLS, they are actually analogous to optical channels and both - the label switch path and wavelength routers, they have of course, they have separate data and control planes and the wavelength routers have separate data planes in the form of wavelength routing and the labels switch routers of course are acting on the IP labels.

So now, the LSR, the edge LSR, it provides virtual point to point unidirectional LSP and the wavelength router will provide point to point light path. While, the LSR will maintain the next hop label forwarding entries, the wavelength router maintains the cross connect table. The wavelength router while toggles wavelength from an input port to an output port, a label switch router will typically do the label shopping paradigm.

So, this is the difference between a standard; so, I should call this to be a standard label switch routers and a standard wavelength router. A standard wavelength router will act on point to point light path, the standard wavelength router will actually maintain a cross connect table and it will do the cross connection of wavelength from an input port to an output port. As opposed to this, a label switch routers actually do the label paradigm, it maintains next hop label forwarding entries and it switches from an input port to an output port essentially a packet.

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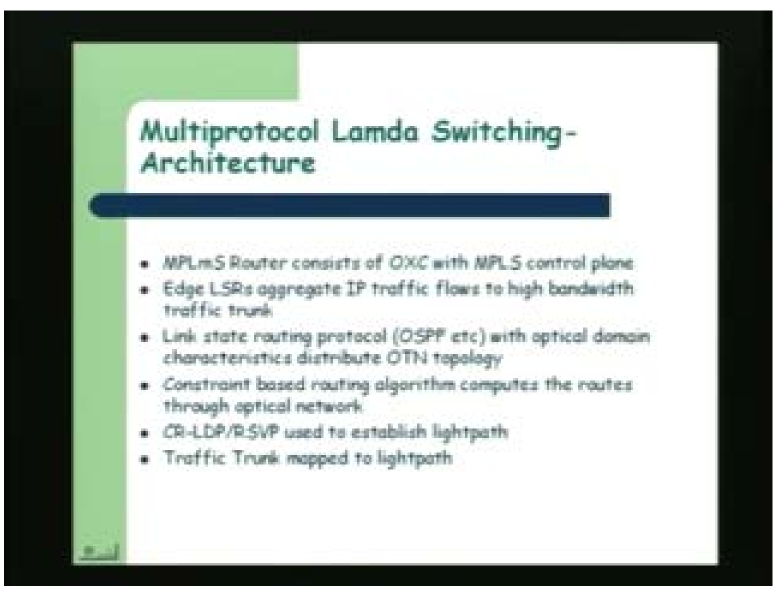

So, these changes need to be incorporated to an MPLS and this gives rise to what we call as the multiprotocol lambda switching. So, instead of label switching, we have this new term which is called as the lambda switching. So, what we are saying is that in the integrated optical peer

model, in the core of the networks; optical cross connects or wavelength routers with MPLS as the control intelligence are nothing but multiprotocol lambda switch routers.
So, instead of this L being standing for the labels; now, it stands here for the lambda. So, this multiprotocol lambda switch routers, essentially they are optical cross connects with MPLS as a control plane and at the edge, this LSR will aggregate the IP traffic flows to high bandwidth traffic trunks. The link state routing protocol like OSPF etcetera with modifications to take care of the optical domain characteristic, they will distribute the optical transport network topology.

We then have constrain based routing algorithm which will compute the routes through the optical network and in this constrained based routing algorithms, we can take into account the constrains related to the bandwidth or traffic engineering capabilities and then compute the route through the optical networks.

Finally, we can use signaling protocol likes CR-LDP or RSVP to establish the light path and that the traffic trunk at the edge of the networks can be mapped to the light path.

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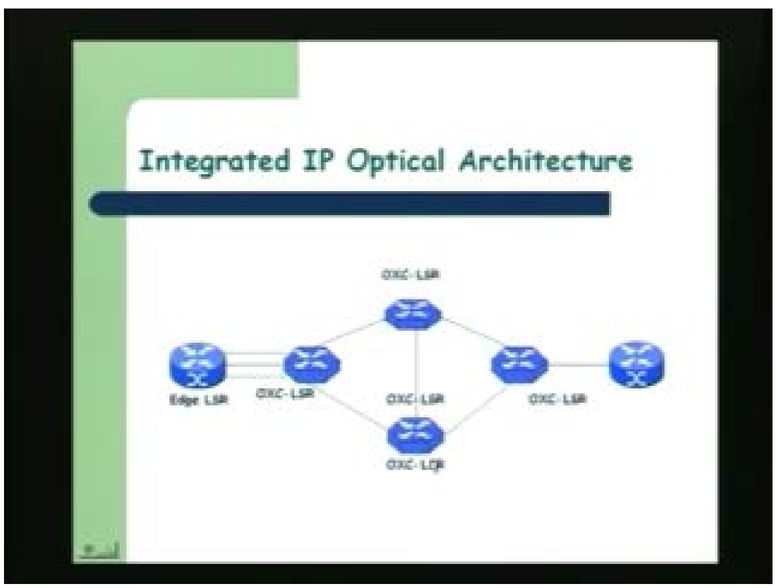

So, the process if you see in this is something like this that in the core of the network, you determine the light paths and this light path, you determine by using routing protocols like OSPF etcetera and you have to make modification to the OSPF to take care of the optical domain characteristics. So, you distribute the optical transport network topology. Then you use traffic engineering criteria and then you determine a path from one node to another node by using some constrained based routing algorithms and then at the edge of the networks, all the IP flows which now needs to be forwarded onto the optical networks; you aggregate them into the traffic flows, you aggregate this traffic flows onto the traffic trunks and these traffic trunks are then mapped to the light paths and then the traffic can be switched in the optical cross connect.

So, when the light paths are actually are provisioned in the core of the networks, in the wavelength router or in the optical cross connect; this cross connect tables are setup and then the traffic trunk can be can be switched because they have been mapped to the light path and the wavelength routers essentially will cross connect these light paths. So, what is the difference therefore between the labels and the label switch path that exists in the traditional networks and that exists in the multiprotocol lambda switch routers or a multiprotocol optical router?

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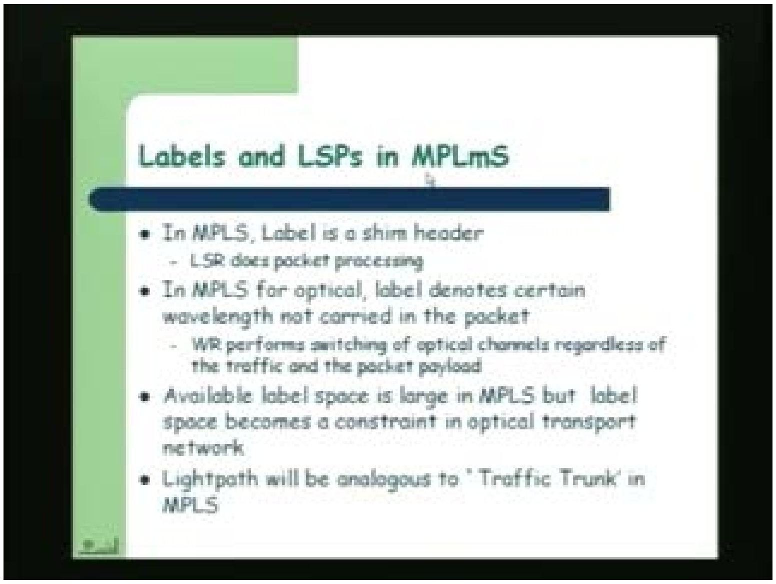

Now, as you can see in MPLS, a label is basically shim header in a standard in a standard MPLS router and there the label switch router does some packet processing. For example, it decrements the TTL count, then it looks at the label, it determines that on by looking at the label, it determines the next hop for forwarding and it also determines the label, the next label that needs to be used. If we have used a labels stack, then it will do the push and pop operation as well by looking at the outer label and then popping it off and forwarding the packets.

However, in optical domain, really a label is syn… with wavelengths; the labels are the same as the wavelength and the wavelength are not carried in the packets. So, the wavelength router performs switching of the optical channels regardless of the traffic and the packets payload. So therefore, the difference is that the switching in the multiprotocol lambda switch router is of the wavelength and not of the labels which is there in the, which is actually a header in the optical packets.

So here, the wavelengths are actually switched. So, a label here is analogous to a wavelength. Now, you can clearly see that in the label switch router, the label is 20 bit and therefore between 2 MPLS nodes, ideally speaking you can have 2 raise to power 20 labels switched path. So, around one million label switch path can exist between 2 nodes. Now here, label in optical network is analogous to a wavelength and you cannot have such large number of wavelength.

So therefore, the available labels space in the optical network is very limited and therefore only a limited light path can be provisioned. So, while the granularity of a FEC in the MPLS node as you can, as we are discussed can range from an application flow to a very coarse which is actually a traffic trunk. In the optical networks you can actually use light path only for forwarding a traffic trunk. So, it is really necessary that you aggregate all these flows into a traffic trunk and then map the traffic trunks onto the light path because available label space is actually restricted or limited.

So, this is what a point here is that the available label space is large in MPLS but label space actually becomes a great constrained in optical transport network. So here, the light path are basically analogous to the traffic trunk in the MPLS networks. The granularity of an FEC or a label switch path cannot be broken down to an application level flow as in a standard MPLS based network.

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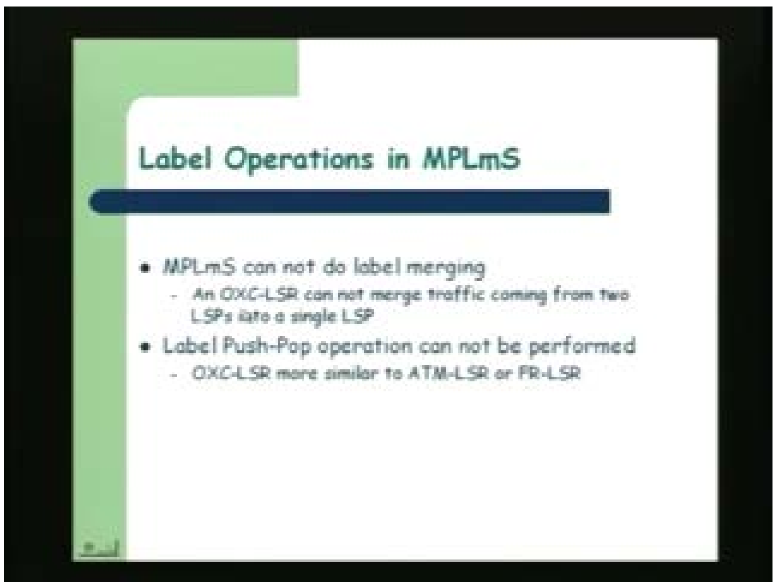

Now, what are the label operations in the multiprotocol lambda switch routers? Note that in standard MPLS you can do various operations. For example, several LSPs you can nest it into a bigger LSPs and you can do a hierarchical nesting of the LSPs. You can do push pop and swop operation on the label. None of such operations are possible in the multiprotocol lambda switch routers. So, it cannot do a label merging also. So therefore, an optical cross connect based label switch routers cannot merge the traffic coming from 2 LSPs into a single LSP.

Now, this is possible to do in standard MPLS routers but it is not possible to do in an optical cross connect based MPLS routers. Similarly, the label push and pop operations cannot be performed. So, in that sense you can see that optical cross connect or label switch routers are more similar to an ATM based LSR rather than to a generalized IP based MPLS router.

So, they are more akin to the MPLS LSR. As you can see, in the MPLS LSR, you cannot have a hierarchy of a virtual circuit path, only one hierarchy is defined that is a virtual circuit path are bundled into a virtual path. You cannot have an arbitrary hierarchy of the virtual circuit path. So therefore, the difference of the MPLS based optical cross connects or a wavelength router is very similar to something like an ATM LSR. In a IP MPLS based router, you can actually have any hierarchy of the or any aggregation of these label switch paths into a bigger label switch path. What are the other challenges?

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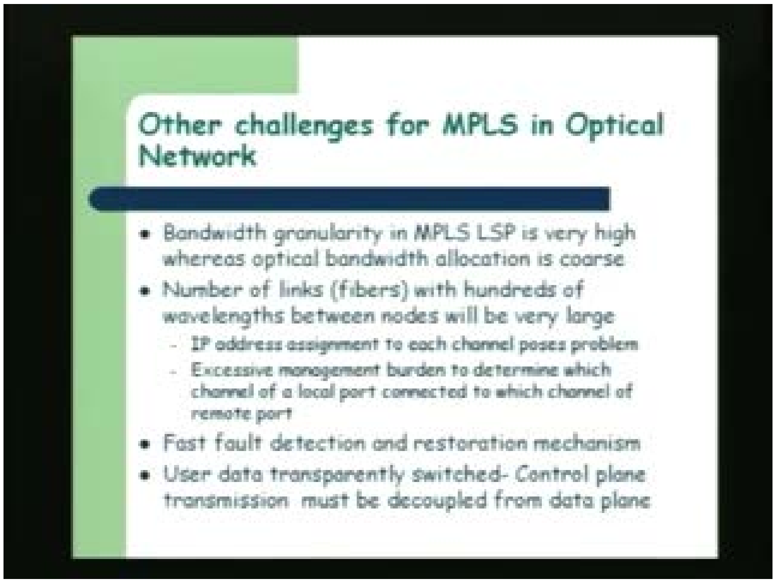

There are other challenges for making MPLS as the common control plane including in optical networks. The other some of the other challenges are the bandwidth granularities in MPLS LSP is very high, whereas the optical bandwidth allocation is quiet course; thus, with this point we have already discussed.

Now, more over the number of links or the fibers with hundreds of wavelength between nodes will be very large and that leads and therefore we need to do an IP address assignment to each channels that poses a problems and also there is an excessive management problem to determine which channel of a local port is connected to which channel of a remote port.

So, these are basically the practical deployment problems that will arise when you are using wavelength base routers and of course, we need to then have fast fault detection and the restoration mechanisms also. So, you need to setup alternate light paths or backup light paths and user data is transparent user data is transparently switched. So, there is no processing of the packets here in the optical cross connects or wavelength routers.

So therefore, the control plane transmissions, it must be decoupled completely from the data plane because optical cross connects or wavelength routers, they really do not process the packets. So, they do not look at the headers of the packets to determine whether it is a controlled packet or whether it is a data packet and then take a decision. So therefore, the control plane transmission must be completely different than the data plane transmission in the optical networks. So, these are the some of the challenges which needs to be met when using of MPLS as the single control plane in optical transport.

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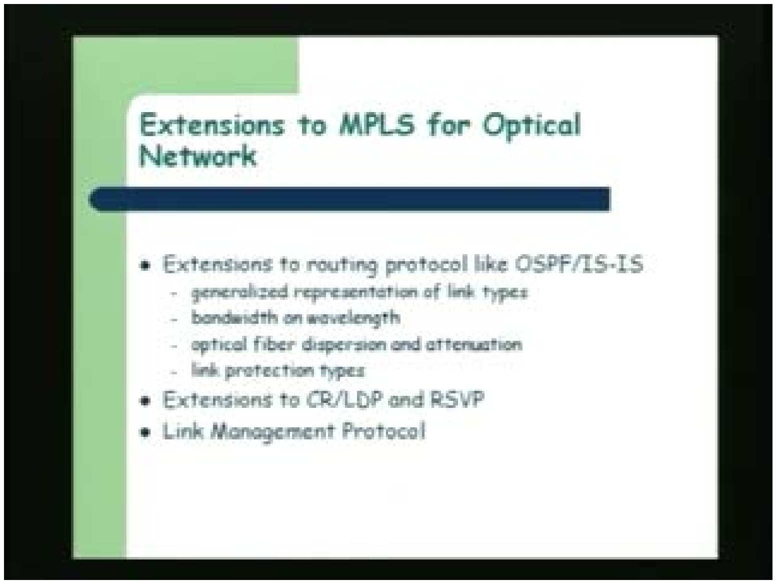

So, that requires certain extensions to the MPLS for optical network. As you have already said that in the core of the networks, when we are using OSPF for distributing the optical transport network topology, you actually made may require extensions to OSPF also and when you setup these traffic engineered light path in the core of the networks, then you also need signaling protocols to convey this light path to the optical cross connect.

So therefore, you need extensions to the singling protocols also. So, whole of these, extensions are required and so extensions to routing protocol, as you can see are required like extensions to OSPF. So, you need to introduce the concept of generalized representation of the link types, you need to introduce the concept of bandwidth on the wavelength, we may also incorporate some times properties of the optical fiber also like optical fiber dispersion and attenuation characteristic.

Now, this is interesting because we may take into account the optical fiber dispersion and attenuation characteristics also to determine the best possible path and then the link protection types. So, these attributes and extension need to be done or added to the routing protocols like OSPF which are used to determine the light paths in the core of the optical networks. We also need extension to the existing signaling protocols; basically, CR LDP or RSVP TE which are used to convey the traffic trunk attributes to the label switch routers and then of course, there is a link management protocol that is required to perform the link management.

So, these are essentially the extensions which are required for the existing optical networks when you want to use MPLS as an integrated peer to peer network. So in summary, let me just summarize our discussion on the MPLS based networks and then we will move on to the different topic.

Now, in summary what we actually saw that historically MPLS was proposed to address the challenges of IP forwarding based on longest prefix match. But it was soon discovered that this is not so much of a serious problem because the forwarding based on forwarding based on longest prefix match have been addressed by using very sophisticated IP forwarding algorithms.

But it was discovered then that MPLS, this label based forwarding paradigm can be very successfully used to address the traffic engineering challenges of the IP networks. So, that is one of the primary applications of MPLS today in the IP networks to address the traffic engineering challenges.

Then IP has its own QS model in terms of integrated services and differentiated services. It was then found that MPLS actually helps that IP QS model. So, by extension of this differentiated services and integrated services paradigm to the MPLS based network, we can actually provide the quality of service guarantees or can setup the guaranteed bandwidth label switch path or virtual circuit in the core of the networks.

So, actually by using that MPLS can actually dislodge all the advantages that existed of the ATM based networks in the core. ATM was actually able to provide quality of service guarantees or bandwidth guaranteed virtual circuit paths and it was also able to do the traffic engineering challenges by using virtual circuit routing. Both these concepts were now incorporated in IP MPLS QS router. So, that solves not only this problem but it is also acting now on the variable length IP packets. So therefore, you do not have the additional over head of segmentation in reassembly.

Moreover, a single IP based paradigm is an operation; you do not have a problem in terms of excessive management. So, that problem gets resort. Even though, I must say here that an additional problems get introduced in terms of operations administrations and maintenance of the, and provisioning of these MPLS based networks and that is still an active open research area.

As an as an off suite or as an byproduct of the traffic engineering capabilities of the MPLS, we saw that it has a great potential of becoming a controlled plane for the optical cross connects or the optical transport networks also. So, there another interesting applications that has or that has come up in the optical cross connect is that that by making extensions of the MPLS networks to a generalized frame work which is called as a GMPLS or generalized multiprotocol lambda switch routers, we can also have an application of the MPLS to be a single unified control plane for the optical cross connect. That is another second enabling application of the MPLS. So, traffic engineering, IPQS, control plane for optical networks; these are the 3 major enabling applications of the MPLS networks.

Now, there are several by product applications sort of having this traffic engineered load balanced path in the optical network. You can provide virtual private networks kind of applications over an MPLS network. So, this IP VPN model can now work over an MPLS based network also giving a rise to what we call as an MPLS VPN networks. We have not discussed that aspect in our lectures but that is another interesting applications of the MPLS based networks.

So, in summary, I would say that MPLS provides a powerful frame work for traffic engineering as well as the control plane for the next generation next generation IP networks based both on pure IP forwarding or based on optical cross connects in the core of the networks. So, before we close our discussion on the MPLS, I thought let me just briefly tell you what work we have done in the space of MPLS networks. So basically, let me just given you in overview of our MPLS based network.

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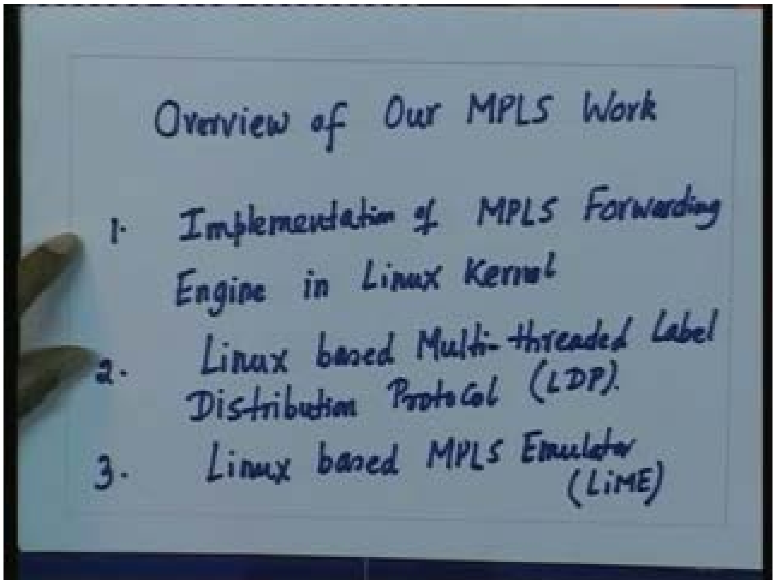

We have developed an implementation of MPLS forwarding engine in Linux Kernel an MPLS forwarding engine in Linux Kernel and we have also done a Linux based a Linux based multi-threaded label distribution protocol which is LDP and then we have a Linux based MPLS emulator. So, these are the 4 aspects we have developed.

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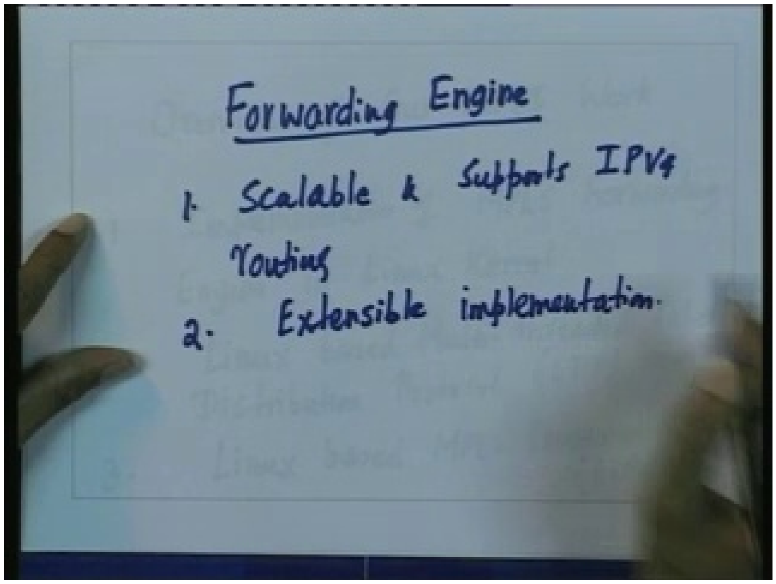

Some of the features which I would like to tell you of this forwarding engine are some of the features of our forwarding engine are forwarding engine feature which is implemented in the Linux Kernel is that it is quiet scalable and we have deployed and we have used it in the Linux Kernel and supports IPV 4 routing currently and supports IP V 4 routing and it is extensible also. So, the implementation is an extensible implementation as well.

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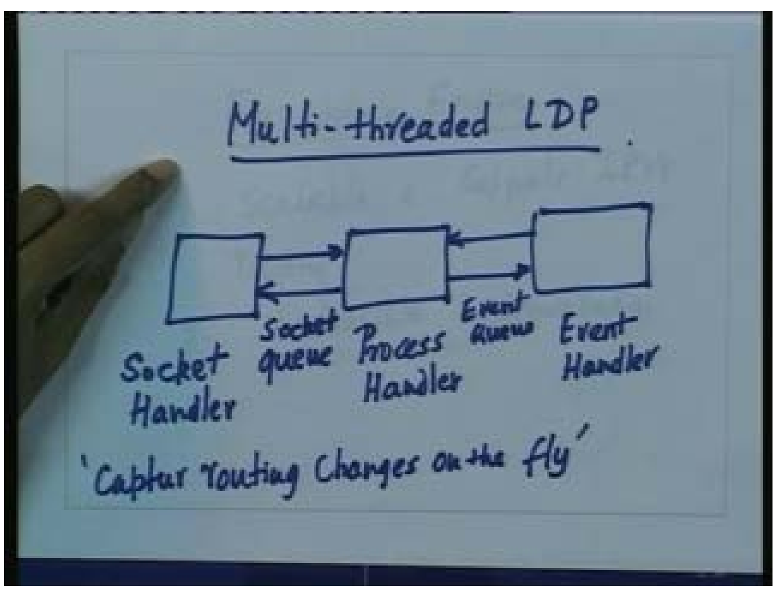

As far as the label distribution a protocol is there; so, the multi-threaded label distribution protocol which we have devolved, so a multi-threaded LDP is so, it is like there is thread for socket handler. So, the threads are there are 3 threads, essentially the 3 main threads; there is a socket handler, there is a process handler and there is an event handler. So, this a socket handler and this is a process handler and this is an event handler.

So, it manages the socket queue and there are even queue here, here is an event queue and these are socket queue here. So this can so this design can automatically capture the routing changes. So, it can capture the routing changes on the fly. So, it can capture routing changes on the fly and it can perform the corresponding actions successfully. So, the other thing is that we have developed is a Linux based MPLS emulator.

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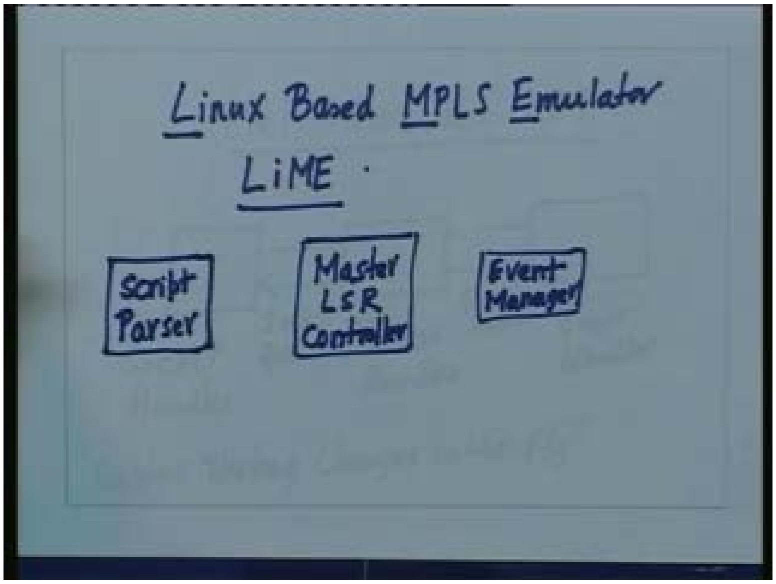

So, this is a third thing that we have developed is Linux based MPLS emulator. So, this is Linux based emulator which we call it to be LIME and this is like… The motivation really was to develop it as a protocol development environment and it can also be used to test the traffic engineering algorithms and so on. So now, this is so here it leverages on the switching engine design that we have done it in the Linux Kernel and also the multi threaded label distribution protocol. So, it is leveraging upon these 2 works our Linux based MPLS.

So, let me just tell this emulator has been designed. So, the top level view is that there is a master LSR controller. So, there are 3 major components here is that master LSR controller and then there is an even manager and then there is of course, a script parser. So, script parser means any topology you can give through TCLTK script and the script parser then is a topology that the knowledge about the topology of the network comes to a master LSR controller and an event manager essentially manages various events in the emulator.

So, this entire implementation, both the multi threaded design of the label distributing protocol the switching engineering Linux Kernel and the LIME all are available in the public domain which people can download and use it for their reference purposes. Many people have been actively using this design.

There are of course future extensions that are required to be done in the LIME; particularly, current support includes only the provision of static label switch path, we yet to incorporate the establishment of the dynamic LSP based on the routing changes. So, this extension still needs to be done. So, this is the word that has been carried out in the area of MPLS domain here at IIT Bombay. So, this concludes my discussion on the MPLS networks, the motivation for its applications and what work actually we have done here to demonstrate the concept.

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