Video 24

And here is an in depth example of how network address translation works. Let's imagine that there is a host with IP address of 10.0.0.1 which then needs to send a datagram to 128.119.40.186 on the port 80. We know that's going to be a HTTP transaction so when the packet hits our first router the network address translation table is going to take the original address and the original source port and map it to the new address on the WAN side on the Wide Area Network side to a new IP address and a new source port. Once the packet reaches our destination it is going to reverse hopefully you remember that from previous lectures and when it comes back to the router it is going to find its way to 138.76.29.7 that's the routable IP address on the network. When that packet arrives to our router the network address translation table is going to map it back to the original host of 10.0.0.1 and the original landside port of 3345 and that's how network address translation works by mapping our inside information to the outside information of the network.

Video 25

And we are now going to take a look at the routing algorithms. But before let's recall the interplay between the routing and forwarding. Forwarding takes the packet coming into the incoming port processes it does the look up on the destination information of the packet itself and then forwards it through the router. Routing algorithm is responsible for maintaining the path through the network to make sure that the packet actually reaches the destination. And now let's take a more specific look at the algorithms themselves.

Video 26

Here is an example of a graph abstraction which depicts the actual network itself. You could see the routers that are shown with the letters of the alphabet and the links that connect those routers. You could also see the numbers above those links. What does that mean? Well that means that each individual link may have a different cost to it it may be the actual cost itself some links are more expensive than others or the cost may be assigned based on bandwidth or length or delay or other parameters. The key question is how do we determine the least cost path through the network? And the answer is that's what the routing algorithm is for. We actually construct the network using different algorithms which allow us and help us to develop that least cost path utilizing different information provided to us by the routers and by the assigned links.

Video 27

There are different types of routing algorithms and their classifications. Some of them are global or decentralized and then they are static or dynamic. Global algorithms mean that all the routers have complete topology about every single router of the network itself. Decentralized algorithms only maintain the information within the router itself and its neighbors so it is kind of like you know your neighbors versus you have the entire view of the whole network itself. And then the static algorithms basically mean that the routes are assigned and maintained statically and dynamic means that the algorithm itself converges and the cost of the links changes and subsequently changes the algorithm based on a state of the network and what it is really happening. So there are delays in some part of the network for example the dynamic and global algorithm will actually change the topology and route the traffic through different parts of the network itself.

Video 28

So all these different types of routing algorithms are actually used in different scenarios. On smaller networks we would usually use decentralized and statically routed algorithm because it is easier to actually construct the network manually. On large corporate networks we would use global and dynamic algorithms but they are also more expensive and much more complex to develop and to maintain. Now let's take a closer look at the algorithms themselves and how they are developed. Next on our list is the link state algorithm.

Video 29

So an example of a link state algorithm is something called Dijkstra algorithm. Dijkstra allows us to develop the least cost path through the network from source to destination using the calculations of individual least cost path. For example how do we get from U to Z? If our computers are attached to the router U and our server is sitting somewhere behind Z? Our first step is we are defining our neighbors and finding what is the least cost to one of them in this particular case it would be the router W. So we move the packet the algorithm would say "our next hop is through the router W". We then would look what is the next least cost path? Here you will see where do we move from UW? Well based on this diagram we would move to X right because the combination from U to W and W to X is three plus seven but now we have a direct jump from U to X with the cost of five. And if you follow this algorithm through the network you will see how the line would be constructed and the least cost will be developed by going one by one and comparing where we are to destination where we are back to the source and what is the least cost path from individual router where we sit. Eventually we will develop that line from U to W to V Y and Z and that's going to be our least cost path through the particular network.

Video 30

Another example of the Dijkstra algorithm or another way to look at that is to actually look at the example of the forwarding table that would be inside the router on our input ports. You could see that all of the destinations are listed and then the links that we would take are also assigned to those destinations. So if the packet arrives and the destination address for example is on the router Y we would know that we would have to take the link U X to get there.

Video 31

An example of a distance vector algorithm is something called Bellman-Ford algorithm. The algorithm here works a little bit differently by looking at the least cost result of the summary of the routes. So we take a few routes together we sum them up we find which one of those sums is the smaller one and that's what becomes the path through our network. The key idea here is that from time to time each node is going to send its distance vector estimation to its neighbors the neighbors are going to look at that process it and say "uh-huh I remember we can go that direction or this direction" and then as the network changes and the links and routers go up and down the distance vectors to a particular destination will change. That's the difference between the link state and the distance vector protocol.

Video 32

So if we compare distance vector and link state algorithms each of them bring different value and have different pitfalls when they are compared side by side. With the link state algorithm with the end nodes we have a large number of messages that are sent because remember it is sent throughout the entire network. Distance vector only exchanges route information with its individual neighbors. If the routers malfunction for example link state algorithm can advertise incorrect link cost where the distance vector algorithm will advertise incorrect path. Think about this for a minute incorrect link cost may result in a delayed delivered of the packet incorrectly advertised path may result into non-delivery of the packet but as we discussed before distance vector algorithms work much better in smaller networks where we can preprogram them together and link state algorithms are usually used in a large multinational across the world big networks which have many different routers and many different links. There is also difference in speed of convergence of each of those algorithms where one is going to be substantially slower than the other but put altogether the selection of the algorithm is really dependent on what we are trying to accomplish and what size of the network we are trying to build.

Video 33

So far we looked at different types of routing algorithms but in reality those were idealizations of what the network would actually look like. Typically we wouldn't be able to store all of our multiple many destinations in a single forwarding table we wouldn't be able to create one single routing protocol that runs throughout the entire Internet. So we look at things like hierarchical routing which allow us to actually do routing through the Internet effectively and efficiently. It allows us to create administrative autonomy where somebody controls certain portions of the Internet and we can have different smaller networks communicate with each other where we don't have to install all of the different destinations in those forwarding tables. Hierarchical routing means that we take certain group of routers and we put them inside something called autonomous system routers in the same autonomous system would use the same routing protocol and they would look over each other but they would not know of the millions of other routers that exist everywhere else. They would know of other autonomous systems so by aggregating these routers together in an autonomous system we create something called hierarchical routing. We then interconnect autonomous systems with each other and we only advertise specific information about autonomous system in some of these destinations as opposed to advertising all of the different routes within the autonomous system. That allows us to collapse the number of different routes that have to be inside the router and only communicate through border routers if and when we have to leave that autonomous system. It also allows us to segregate the traffic by function or by geography. People in Americas that are part of the autonomous system would typically tend to communicate more with other people within their geography so autonomous system allows us to also use the traffic more effectively and efficiently.

Video 34

So what are some of the tasks of the autonomous system? Suppose router in the autonomous system 1 receives a datagram that is destined within that autonomous system. We would then just simply forward that. But if it receives the datagram that is destined to a destination host outside of that particular autonomous system it needs to learn which route it has to take outside of the AS to go through to its destination. We would have to then speak to our border routers that connect our autonomous system to another border router in another autonomous system and understand the path through. Once we learn that we will include that route into our forwarding table and from that moment on we will be able to communicate through our border router to other autonomous systems and send our packets to destination that are outside of our AS.

Video 35

We are now at a place where we are going to discuss actual protocols that are used today to move our packets from source to destination on the Internet. There are different types of protocols that exist today that allows us for the Intra-AS Routing RIP which stands for Routing Information Protocol. It is one of the older protocols it is not used very widely today but it is still used on smaller networks it is a distance vector protocol. The other two are used widely one is called OSPF Open Shortest Path First which actually does what it means develops open shortest path first and also develops alternative path. And then we have some proprietary protocols from equivalent manufacturers like Cisco which is IGRP and EGRP those are usually used on a private network when we have to build something for ourselves.

Video 36

Routing Information Protocol it was originally developed in the 1980s and it was originally included within Unix distribution. That was long before routers were actually dedicated devices and big computers were used as routers. As I said before it is a distance vector protocol it has a number of hops before the packet is dropped by the router so there is a counter information inside the packet and the distance vector exchanges information with its neighbors every 30 seconds in response to the message. Let’s take a look at an example of how the RIP protocol actually works. Let’s imagine that we have this type of network with destination subnets inside the forwarding tables of each individual router. If we look at the destination subnet W the next router is A and the number of hops to destination is two. Destination subnet Z the next hop router is B and the number of hops is seven. But once we develop a new path once the new link is brought on board the forwarding tables using the distance vector algorithm are going to change and destination information to Z will change. The next hop router will become A and the number of hops will become five. So once those neighbors exchange the information about the new router that came on board or about the new link all of the routers are going to reconverge and update their forwarding tables to accommodate for the new information and to develop the new least cost path.

Video 37

What do we do if there is a link failure and how do we cover? Actually if no advertisements are heard within 180 seconds the neighbor or the link are declared dead and in that case we are going to update the forwarding table inside our router and we are going to have the routing algorithm develop a brand new path to the destination. The router routes to the particular vendor are going to be invalidated the new advertisements are going to send two neighbors acquiring about the information to the route. Think about Google Maps and if there is a construction on the road the algorithm is going to reroute you through different path to your destination. This works somewhat similar to that.

Video 38

And next on our list is OSPF Open Shortest Path First it is an open publicly available protocol which means it is not specific to the manufacture. Routers from different manufactures can interconnect using this protocol and understand each other. It uses link state algorithm to move the packets back and forth it has a topology defined in each individual node and it has OSPF advertisements that will get carried through the network one entry per neighbor. It has substantial improvements over RIP it has got built in security think about this all of the messages have secure identifications within them so somebody cannot maliciously reroute our traffic. It allows multiple paths to destination creating substantial more efficiency and hierarchical OSPF is used in large networks used in large domains if you will to route the information because it is easier to converge and easier to maintain as opposed to other different algorithms.

Video 39

Here is an example of the hierarchical OSPF. You can see the number of different devices and technologies that are part of this diagram we have boundary routers we have backbone routers border area routers and internal routers within our autonomous systems. This was a two level hierarchy where we have a local area and a backbone the link state advertisements are all limited to a particular area where the routers are defined so within each particular area those links that advertisements are going to be going only to those routers and they are not going to flood the entire network. The area border routers are going to summarize distances to the networks in its own area and then advertise them to other area border routers. The backbone routers are going to run OSPF only to connect our backbone together and then finally boundary routers are going to connect to other autonomous systems. This way we can limit the number of information we have to exchange with our neighbors only to either the backbone or to our autonomous systems where the routers are operating.

Video 40

And finally Border Gateway Protocol BGP it is the protocol that’s de facto glues the Internet together it is the protocol that currently operates throughout the entire Internet and allows us to send packet from source to destination throughout the entire world. Errors in BGP and they are known actually resulted in some of the biggest outages in the known history you can click on this link to learn a little bit more about one of those outages. BGP is divided in two subprotocols iBGP and eBGP. As you can imagine eBGP obtains subnet reachability information from neighboring autonomous systems iBGP propagates that information inside the autonomous system to all other routers. Let’s take a closer look at BGP itself.

Video 41

BGP unlike OSPF and RIP has routing policy that is built in to the protocol which means that not only we can route by developing a least cost protocol from source to destination but we can apply other metrics to our routing. For example let’s say we do not want to route information from one Internet Service Provider to the next because we get no revenue for that. We can define a policy on our router on our interface that says if we see packets coming from source A to destination B do not forward them. Create a policy that actually blocks that particular forwarding path and does not advertise it back to the network. We can use policy for different technology such as for example let’s route voice or let’s route video a BGP policy may say if we detect video on the network and it is a broadcast going to our employees route it differently as opposed to our regular email packets. It is a very useful feature to have policy based routing implemented on these routers because we can really move the content where it needs to be from source to destination rather than just using least cost path algorithms.

Video 42

So why do we have this different intra and inter AS routing protocols and technologies in place? Well we can actually apply policy to different routing we can say inter-AS routing administration wants control over the how the traffic is routed and who routes where. Where intra-AS routing is a single administration where no policy decision are made. There is a scale component to that where hierarchical routing can allow us to save table sizes by not including all of the routes inside our routing table. And then finally there is a performance component where it allows us to focus within the intra-AS on performance and inter-AS through the backbone on policy which is going to dominate over performance but allows us to move the packets really really fast from source to destination.

Video 43

And finally in this lesson we are going to look at broadcast and multicast routing. Why do we need those different functions? Well the broadcast routing is needed when in fact we have to reach all of our hosts on a particular network right when we have to send one packet that reaches everyone. It could be big advertisement it could be DHCP packet or it could be something else. How can we achieve broadcast routing? How can we make it more efficient? There are different ways to do that. We can use something called in network duplication where we can use flooding or control flooding we can just send all the packets to all the routers and then they are going to forward them through. Or we can use a technique called spanning tree which will basically construct a network path through our network from one router to the next only hitting each individual router once. This way all of the hosts attached to those routers will in fact be reached but we don't have to rebroadcast the packets when they go throughout the entire network in each individual router. Spanning tree is the latest and most used technique when we use broadcasts.

Video 44

In multicasting as a by product or sub product of broadcasting is when we need to deliver packets to multiple but not all of the computers on a particular network. Think about a large building where they may be conducting video classes we may have to deliver that video to ten out of the thirty different classes but we don't want to flood the entire network with that information. So we use multicasting protocols on our routers to define what the multicasting traffic is and then build a tunnel through the routers which will not need to deliver multicast packets so we can connect the devices which are recipients of that particular traffic to the routers which have to participate in the multicast. Logically the multicast routers will appear to be connected directly with each other but physically there are going to be tunnels built through regular routers where devices are not participating in the multicast. It is a good technique to distribute software to conduct online classes or do few different other things.

Video 45

And this brings us to the end of our lesson today we've covered a lot of material we discussed routing algorithms such as Dijkstra and Bellman-Ford. We look at different routing protocols such as RIP OSPF and BGP. We looked through the IP addressing schema we discussed what is inside the router and covered broadcast and multicasting. We are continuing our journey down the networking stack we are going to discuss link layer protocol next time and until then thank you and see you later.