**Multicore Computer Architecture - Storage and Interconnects**
**Dr. John Jose**
**Department of Computer Science & Engineering**
**Indian Institute of Technology, Guwahati**

**Lecture - 13**
**Routing Techniques in Network on Chip**

Welcome to the 13th lecture, today we will continue our discussion on Network on chip. Last day we had the introduction to chip multicore processors and what is the role of network on chip in maintaining the communication infrastructure in such multicore processors. We all know that for any network the crucial component that drives the network is the underlying routing strategy.

Similarly, in network on chip also we have to understand how the routing technology works. A data that is starting from one tile has to reach another tile on the same chip and that is travelling through a shared medium consisting of routers and links. There may be multiple paths that exist. So, we have to find out what is a best path.

In this lecture our discussion will be focusing on the routing algorithms and we will see what are the classification of routing algorithms and see what are the merits and demerits of each category of routing algorithm.

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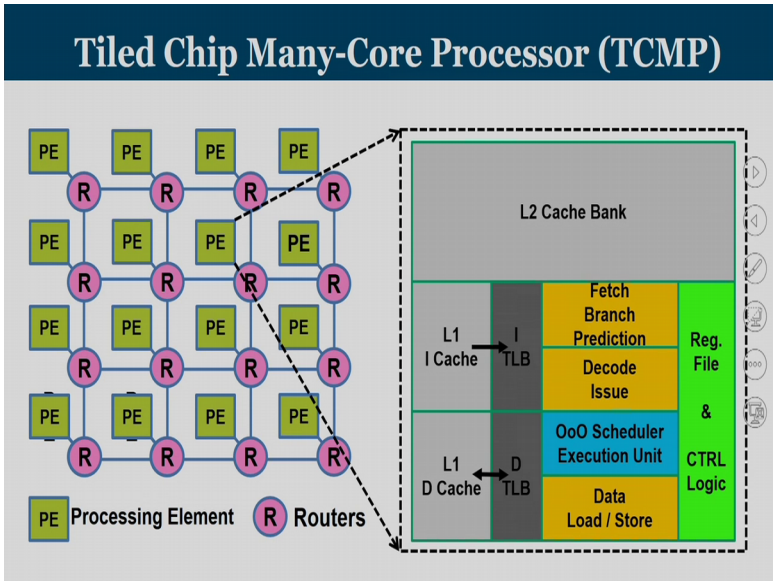

We have seen that in tiled chip many core processors each tile consists of your processors and cache memories and.

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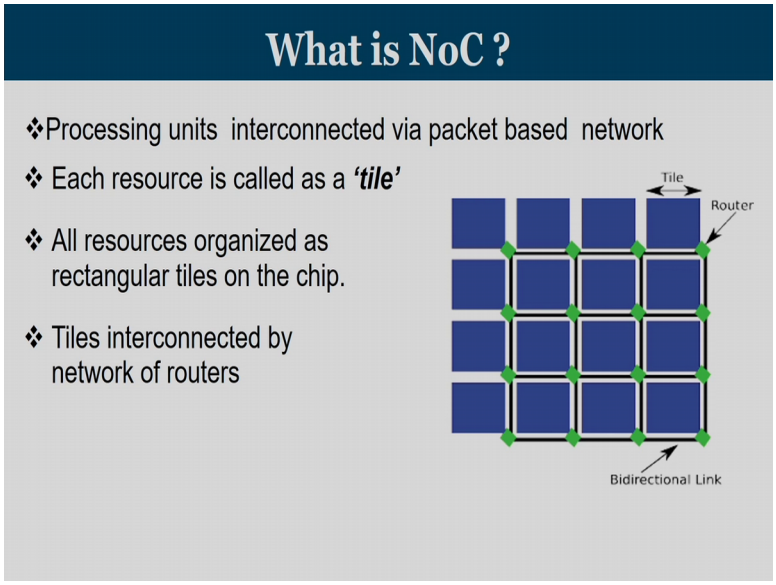


The network on chip is going to connect multiple childs and we have seen that the tiles are organized in a rectangular mesh structure and they are interconnected by a set of routers and links.

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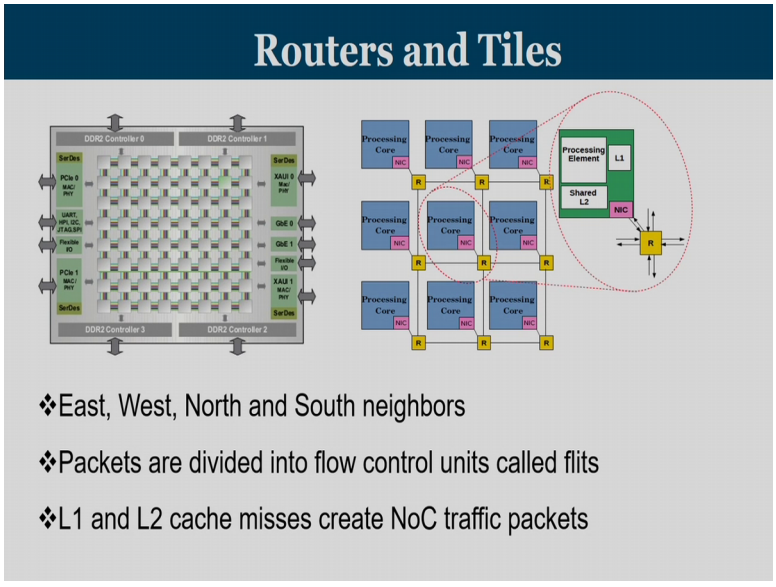


And each of the tile consists of processors, multiple cache hierarchies and tile connected to routers and routers are East, West, North and South neighbors. And packet is the unit

of transfer between one tile to another and these packets are communicated with the help of sequence of flits and flit is the basic flow control unit.

L1 and L2 cache misses are responsible for creation of packets. This much is what we have covered on our last lecture.

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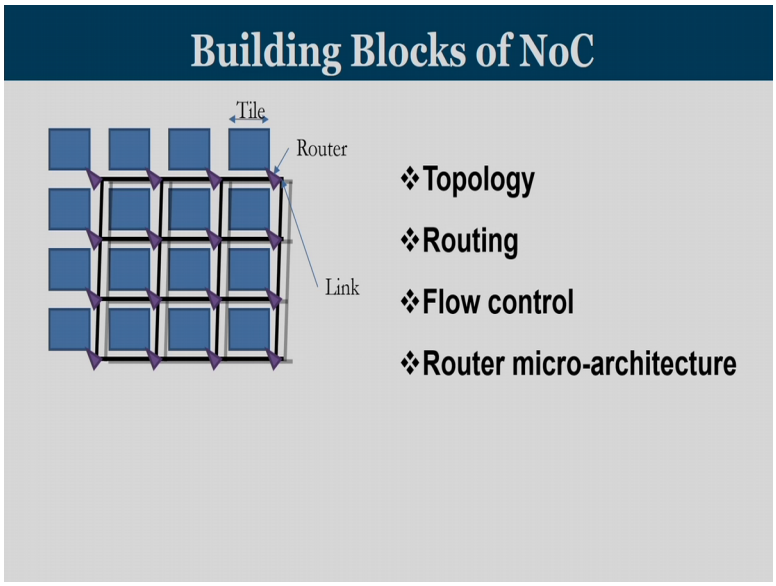


To continue our discussion let us see what are the remaining building blocks, out of the 4 basic building blocks for NoC we have covered topology already. Today our focus will be on routing and the next lecture we will cover up flow control and router micro architecture.

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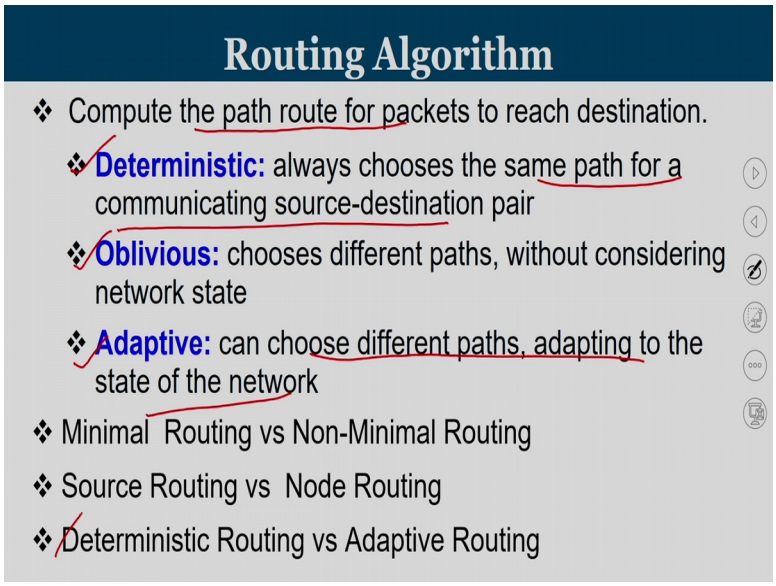


So, what is the job of a routing algorithm? So, routing algorithm essentially compute a path for the packets, to reach the destination. Packets are created from one of those tile and from that tile the packet has to reach the destination and the packet will travel through a couple of intermediate routers and links.

So, routing algorithm helps this packet to travel through the network so, that it can reach the destination. Routing algorithms are divided into 3 based upon how are you going to pick a route. The first one is called deterministic routing, where between the same path you always choose the same path between a pair of source and destination.

So, whenever you travel from A to B if you apply deterministic routing every packet from A to B will follow the same path irrespective of the traffic conditions. Another category of routing is known as oblivious routing where there maybe multiple paths between a pair of tiles A and B. Every time we may choose one among the many paths, but that path selection is not based upon current network status.

So, we cannot call it as a dynamic we are trying to exploit path diversity. So, first time I may use path a 1, second time I may use path a 2, for the third packet it may be a 3. But, the selection of a 1, a 2 and a 3 is not dependent on the run time traffic. But, it is slightly better than that of deterministic routing.

The third one is called adaptive routing where it is an advanced version of oblivious routing. Here, routes will be assigned to packets in such a way based upon the current network status the congestion status of the network. So, we will choose different paths adapting to the state of the network.

So, deterministic routing, oblivious routing and adaptive routing are the 3 different broader classification of routing algorithms employed in network on chip. Where deterministic is prefix route, adaptive is one among the many route that to it is a static algorithm and the third one is see the oblivious is one among the many and the last one is completely adaptive.

We have yet another classification that is minimal routing and non minimal routing. The next one is source routing versus node routing and the last one is what we have seen already deterministic verses adaptive. We will try to understand what are the other types of classifications of routing algorithm. The next classification of routing is minimal and non minimal route.

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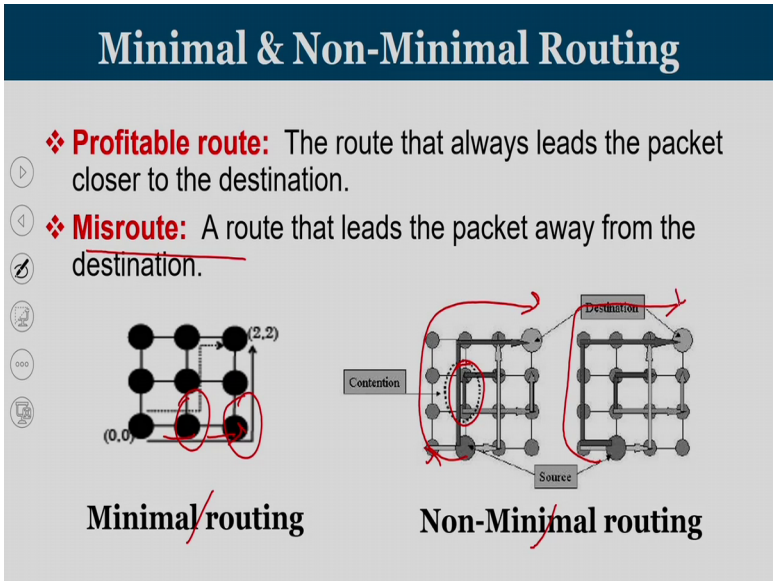


So, we are trying to introduce another terminology called profitable route. The route that always leads the packet closer to the destination is known as minimal routing. So, at every hop the packet is reaching one step closer to the destination. If the routing algorithm is in such a way that after you perform routing the packet is moving to another

node and that node is still more closer to destination. So, if you apply this in every step then we call it as a minimal route or it is also known as profitable route.

So, here we can see that a packet starts at 00 let us say it is going to take one path so, it reaches this neighbor. Now, this neighbor is actually one hop closer to the destination than that of the previous node.

Now, I am taking one more transition, now this node is also one more step closer. So, at every step the packet is reaching one step closer or one hop closer to the destination, then we call it as minimal routing. The other one is called misrouting a route that leads the packet away from the destination.

So, why we need to travel away from destination? Our purpose is to reach the destination. So, under what context under what scenario, where a packet is forced to travel away from destination? In real life also let us say we wanted to travel from a to b depending on the traffic conditions we know that the shortest route in terms of length may not be the best routes.

Sometimes, we may take a longer route in terms of distance, but in terms of time it may be a better route. Similar to that in network on chip also we have the concept of misrouting a route that needs the packet away from the destination.

So, in this scenario we are going to have a context where let say this particular link is going to be busy. If the link is going to be busy then we are going to have a D-touring. So, as long as this link is busy I always have a possibility to explore this route. So, once I explore this route the moment I land up here I am moving one hop away from the destination. This is the way how this routing is been in progress.

So, we have learned 2 types of routing, the first routing is known as minimal routing and the second one is known as non minimal routing. In the case of minimal routing we are moving always closer to destination, in the case of non minimal routing we are moving away from the destination. Why we are moving away from the destination because, certain scenarios taking a D-touring will help us to get around with congestion nodes or nodes which are known as hotspots.

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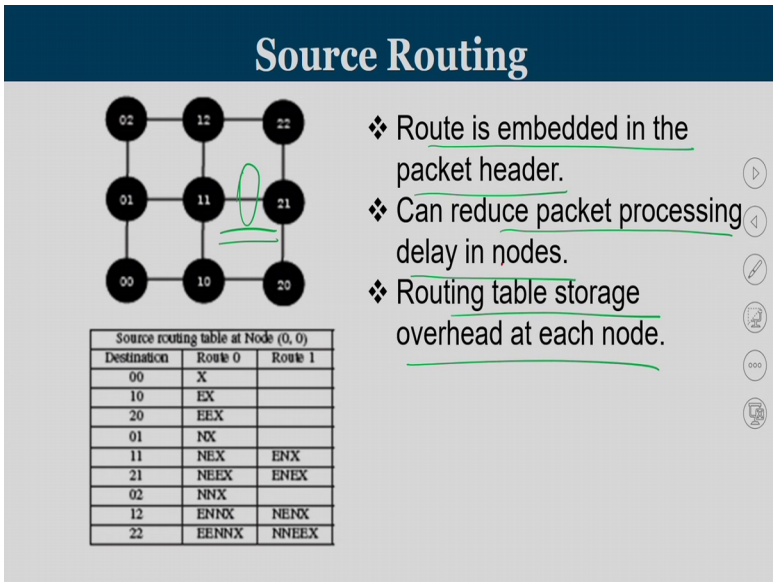


Now, we will see the next classification of routing, this is known as source routing. Source routing is the concept where when a packet starts from the source tile, it knows what are the turns, it is supposed to take at every intermediate junction. We know that when you use a mesh topology, each router will have 4 neighbors, 4 neighboring routers, one in North, South, East and West.

So, when the packet are travel through the network, it may reach junctions, it is a 4 way junction, sometimes you may have to take a North transition, sometimes South, sometimes East or sometimes West. If the turn that you are supposed to take is the direction that a packet is supposed to take is already embedded in the packet right from the source. So, that at every intermediate junction what is the translation that you are looking for? Then if that can be already embedded then we call it as source routing.

So, from the source itself the packet knows what is a path it is going to take, what is the deviation that it is going to make, what kind of turns that is going to make at each intermediate junction is called source routing.

So, in the case of source routing, the route is embedded in the packet header. So, since the route is already embedded in the packet header you should the packet is not incurring any additional delay in the router. You come to the router and you tell what is the route that you want because, a route is already the turn is already mentioned in the packet

header. And using that you take the turn but, how are you going to get this route information?

So, every router need to accommodate a table and the table contains all the details pertaining to every destination in the network. Let us say there are 10 destinations in the network the route to reach all the 10 destinations in the network should be available in each and every router. And the route to reach y from a maybe 1 and the route to reach y from b may be different.

So, the table is going to be totally different for this. So, this table overhead is one problem that is associated with node routing. We are going to talk about the source routing now.

So, source routing is the technique by which the turns that you are supposed to take is already embedded in the packet header, let us now consider an illustrative example. So, consider the case where we have a mesh network, where we have total of 9 routers marked from 00 to 22. As we have already discussed in the case of a source routing, every router need to have a table with it. Whenever a packet is generated from that router we are going to consult on this table and the table contains the route to reach the destination.

So, this is the routing table for node 00, this is node 00 so, this table is incorporated in node 00. How we are going to analyze this table is we are going to have various possible destinations, these are the destinations possible in the network. Now, consider the case like I wanted to reach 10. So, from 00 to reach 10 the transition required is taken East turn that is what is mentioned by East. Then followed by X, X means I have already reach the destination exit. So, East and Exit that is from 00 if you wanted to reach 10 then it is East and Exit.

Now, consider the case I wanted to travel to 21, if you wanted to travel to 21 there exist 2 routes North, East, East X. So, North, East, again East and then you are going to exit. Another possible route that you could take is East, North, East, X. So, it is East, then North, East, X.

So, there are 2 routes that is possible to reach the router 21 from node 00. Similarly, I can have another route also as long as I am only bothered about 2 routes this is sufficient

enough. To reach 22 I can take East, East, North, North, X, East, East, North, North, X. The second route is North, North, East, East, X I can have one more route it is North, East, North, East X.

So, if there are many routes possible my table should be accommodating larger number of entries. So, like what we are consolidating here, source routing the route is embedded in the packet header. Because of this we can reduce packet processing delay, but there is routing table overhead.

The problem with the overhead is this scalability issue; this is a 3 by 3 network consisting of total 9 routers. When the number of routers are going to be larger let say more than 50, then the table overhead is more. And the updation process of the table let us say if there is one of the link is going to be faulty; in that case you have to update all the tables of all the routers that is going to be a costly operation.

So, consider that this link is going to be faulty, the link is faulty everybody who was having an entry from 11 to 21 all the entries are to be corrected which is going to be an overhead.

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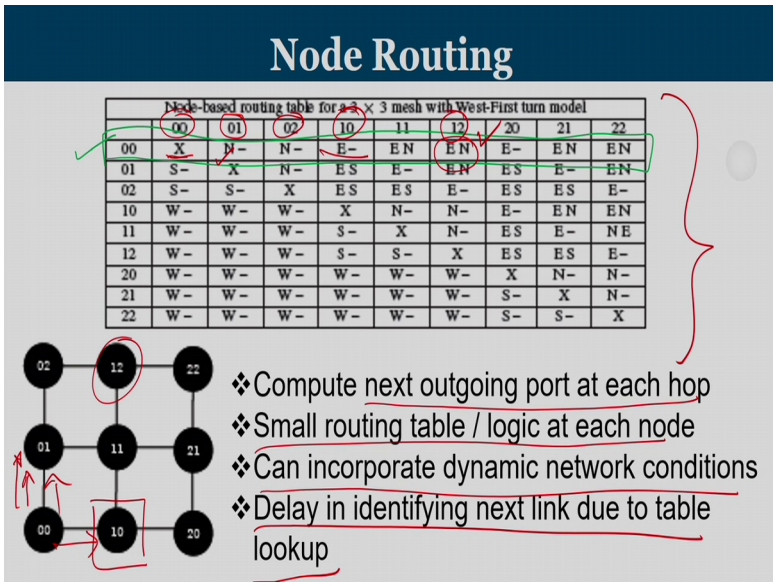


So, the next type of routing is known as node routing. So, in source routing you know the route right from the source, in the case of a node routing all the route transition that you are going to take through your journey; it is not embedded on the packet. We are going to

consult each and every intermediate router. This is similar to the real world scenario where you are travelling from one place to another, you do not know exactly the route, but you know what is the destination.

So, in that case at every junction where there are multiple possible ways to further explore, you may consult somebody I wanted to go to so and so position, that they will tell go straight or go left. So, in the next junction also whenever you have a confusion, you inform about what is going to be your destination and based upon that the person who is there is going to direct you what kind of turn you should take.

Adopting this principle node routing means the packet has the destination address and the routing fabric at each of the intermediate junctions will extract the destination address. And apply in the combinational logic of the routing fabric and the routing fabric will tell you whether you should take a North, South, East or a West turn.

So, in that way the routing technique is not taken right from the beginning, every intermediate router is taking path in the process of sending the packet from the source to the destination. Node routing also some kind of a tabular approach is being conventionally used. In the recent tiled chip multi processors node routing is done with the help of algorithms as well.

Let us now consider this table that is been given here this first row is what is say as the routing table for node 00. Let us try to understand how this table is interpreted. From 00, this entire row is the routing table for node 00. From 00 if you wanted to go to 00; that means, you are in the destination just exit. If you wanted to go to 01 you have to take a North transition. If you wanted to go to 02 also I have to take a North transition.

So, in both traveling to 01 and for 02 you have to take North. I am not going to tell how many North or how many East is, I am really bothered about only what is the next immediate transition that the package should take. So, when the packet is in 00 if the destination is either 01 or 02 the packet has to take a North transition.

Similarly, you see 12, if I wanted to reach 12 the packet can take either East or the packet can take North that is what is the meaning of EN. So, the EN entry means either it can be East or it can be North that is the way how this packet is being routed. Similarly, if you

consider 10 this is 10 and 10 can be reached only by East. So, that is the route that is been given.

So, we will try to understand what are the features of node routing. In node routing the next outgoing port at each hop is computed there is relatively small routing table at each node. So, even though this routing table looks very big, this is actually stored across 9 routers. One row is stored in one router similarly you have 9 routers.

This routing can incorporate dynamic network conditions whenever there is a change that is happening in one pair of routers or some congestion is to be recorded, the entire routing table that is stored across all the routers need not be change, but that was not the case in the case of a source routing. In the case of source routing any change that happens in the network, every routers routing table need to be updated In this case a change that is happening in any portion of the network, only a few set of routers will have to be changed.

But, the problem with the node routing is at each of the intermediate router we are going to have some kind of a processing that is involved. Destination address of the packet is extracted and then this particular packet is going to be studied or further processed and algorithm there is going to find out whether North, South, East or West is been taken.

So, delay in identifying the next link because we need to have a table lookup at every intermediate router.

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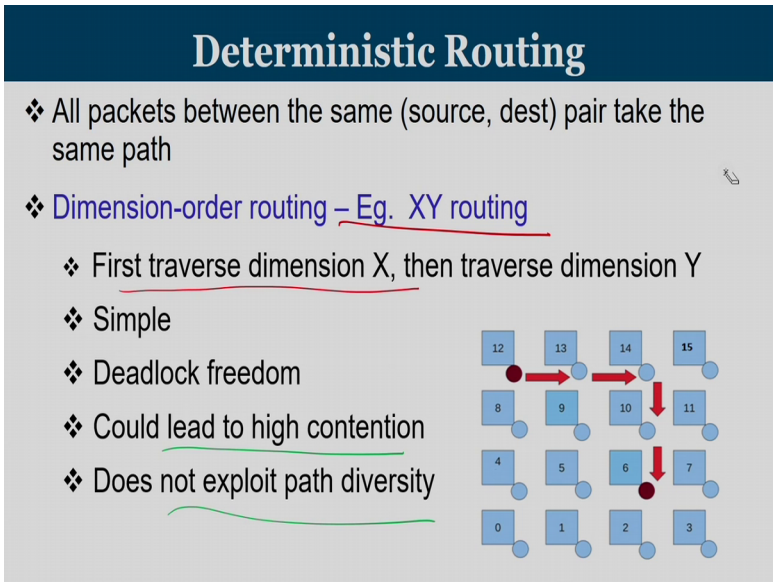


We have seen about deterministic routing, all packets between the same source and destination pair is going to take the same path. The most popular deterministic routing is known as dimension order routing or it is also known as XY routing where the packet first travels in the X dimension followed by the Y dimension.

So, consider the scenario where you have a packet starting from 12 and it has to reach 6. So, the packet is going to take X direction first like this and then take 190 degree turn and move to 6. So, then how will a packet move from 2 to 13 as per XY routing? So, 2 to 13 as per XY routing you travel along X. So, 2 to 1, 1 to 5, 5 to 9 and 9 to 13 that is a way how the packet is moving, this is the most simplest routing, very easy. So, the current router will check what is the destination of the incoming packet. X coordinates are compared, Y coordinates are compared and then you take a call whether it should be in East or West turn or it should be in North or South turn.

But in all cases a packet can have at most 190 degree turn; in it is entire travel time from the source to destination. This is a very simple algorithm, it is having freedom from deadlock and the problem is since every packet from a node to another node is traveling through the same set of intermediate routers, this can lead to high contention.

So, thing of a case that in this case let say there is a heavy congestion at 14, all packets from 12 to 6 can only exploit this path there can be path like this, but we cannot exploit

this. So, any contention in the existing path will delay all the subsequent packets. Path diversity is not there we cannot exploit path diversity.

So, contentions will occur, during contentions as long as we use XY routing there is no way out, we have to go with the contention and wait for the time till the contention is resolved.

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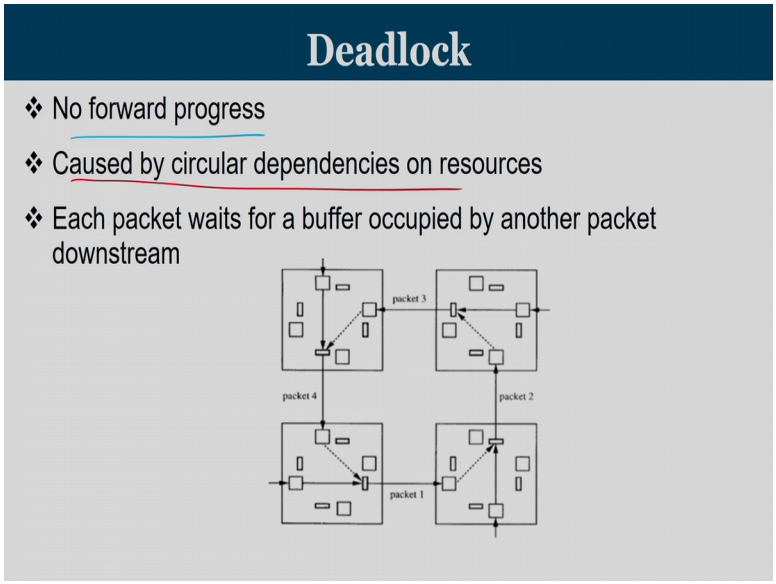


Now, we have already mentioned that dimension order routing is going to resolve deadlock. What is actually a deadlock? Deadlock is a scenario where a set of packets are mutually waiting for each other. Let us try to understand how this happens.

Consider the case that, this is the set of 4 routers and these are all buffers in which packets are residing. These are all buffers whatever you see here. Now, a packet that is sitting in one buffer this buffer is trying to travel to the West neighbor. So, after reaching the West neighbor I am looking for whether this buffer is available for me.

So, a packet sitting in the South input port of a router is looking to get a space in the East input port of its West neighbor. Let us say we will call it as A, B, C and D. A packet in the South input port of A is looking for a buffer which is there in the East input port of B.

Now consider the case a packet which is there in the East input port of B, is looking for a buffer which is there in the North input port of C. Similarly, I can have another packet which is sitting in the North input port of C is looking for a West input port of D. And to

complete the cyclic dependency I can have a packet which is sitting in the West input port of D looking for the South input port of A.

So, this means that there exist a cyclic dependency between packets, a packet is waiting for a buffer in the next router and that buffer is occupied by some other packet, which is intern waiting for some other buffer in another router. Like that you have a sequence of cyclic dependency. Typically it happens across all routers to form a chain and that is what is called deadlock.

Whenever you have a deadlock there is no forward progress that we can make, and this is basically caused by circular dependencies of the resources. And each packet waits for a buffer occupied by another packet downstream. Why deadlocks is happening?

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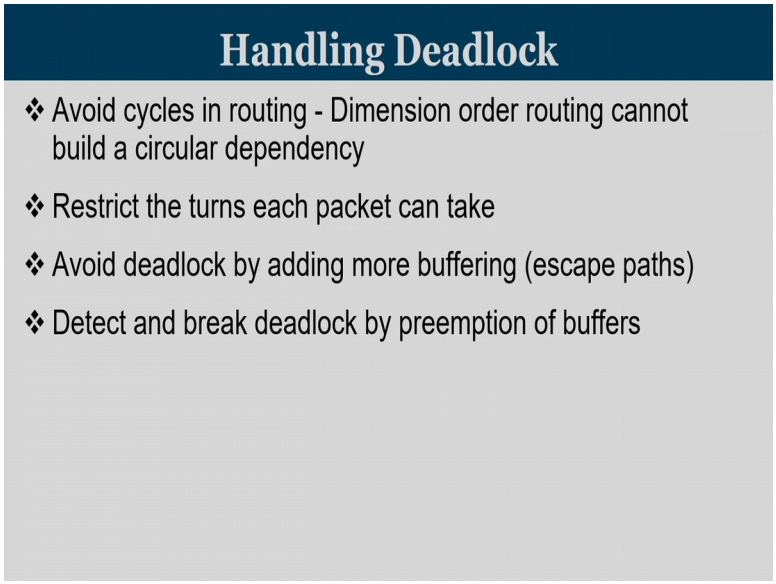


Deadlocks are happening because of the formation of cycles. How can you handle deadlock? You have to avoid cycles in the routing.

So, when you follow dimension order routing, there cannot be any cyclic formation. Because, in the case of dimension order routing either you travel along X dimension and take a South or you take X dimension and going to North or travel to West take a South or travel to West take a North. So, only 4 turns are going to happen when you are going to use dimension order routing.

So, let us try to revisit what are those 4 turns this happens, this happens. Similarly, this happens and at the same time. These are the turns that are happening because you travel along the X dimension then Y you travel along X dimension and then Y. A turn like travelling along Y and turning to X this things would not happen.

So, dimension order routing make sure that a transition along Y dimension is not shifting towards X dimension. But, that is over restrictive in nature, we will try to see how deadlock is been handled.

So, in dimension order routing we are trying to restrict the turn each packet can take. And we can have more number of buffers that can be incorporated such that there can be escaped paths to break the deadlock cycle. Deadlocks can be detected and broken by preemption of buffers.

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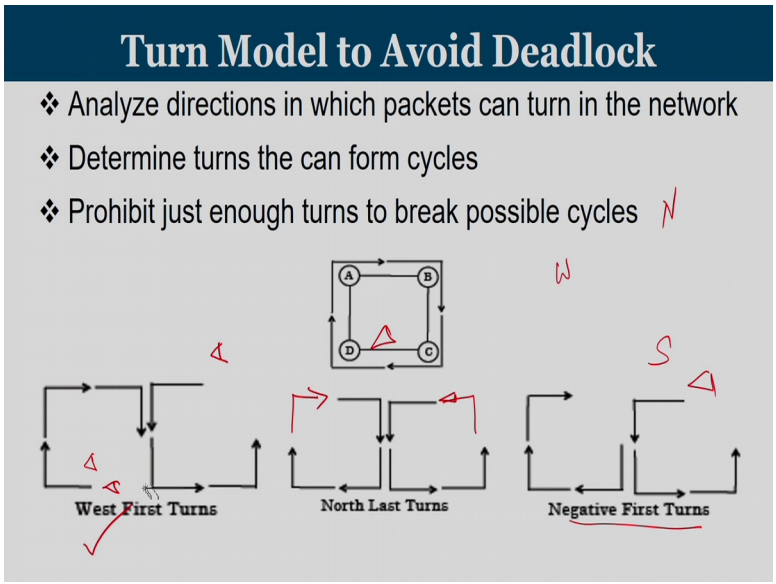


Another classical algorithms since your dimension order routing is highly restrictive in nature, another class set of algorithms were proposed, they were known as turn model.

So, in clockwise dependencies and then anticlockwise dependencies one among the turn is prohibited. So, we know that these are the turns that are happening in order to form a deadlock. In the case of a turn model, the first category of turn model is known as West first turn.

So, these turns what I am drawing now with the pen are not permitted when we employ West first routing. The peculiarities travelling towards North direction and switching to West and travelling towards South direction and switching to West is prohibited. So, whenever you wanted to travel to West direction it has to be taken in the beginning itself.

So, when the destination is relatively to the West of the source router right from the source router take only West turn. At some point of time you may have to take a North or a South turn. Once we are taking a North or a South turn then the no more West turns are prohibited.

So, if at all you wanted to take a West turn take it in the beginning. Once a non West turn is taken no more West turns are allowed. So, in this case in the clockwise direction we prohibit one turn, in the anticlockwise direction also we prohibit ones turn and thereby you make sure that deadlock formation is not happening.

Another category of routing is known as North last routing. Here you can see that these 2 turns are prohibited. Any movement towards North shifting to East is not allowed. Any movement towards North shifting to West also is not allowed.

So, the idea is once you take a North turn then no more X turns are allowed, no more East or West turns are allowed. So, if at all you wanted to travel to the North that has to be traveling at the end that is what is known as North last turn. And the third category is known as negative first turn.

So, whenever you consider as a quadrant East and North are considered to be positive turns, West and South are considered to be negative turns. So, any movement towards negative axis that is towards the South and towards West should be taken first, that is what is known as negative first.

So, once you move to North then West is not allowed, once you move to East then also South is not allowed. So, negative transitions has to be dealt in the beginning itself.

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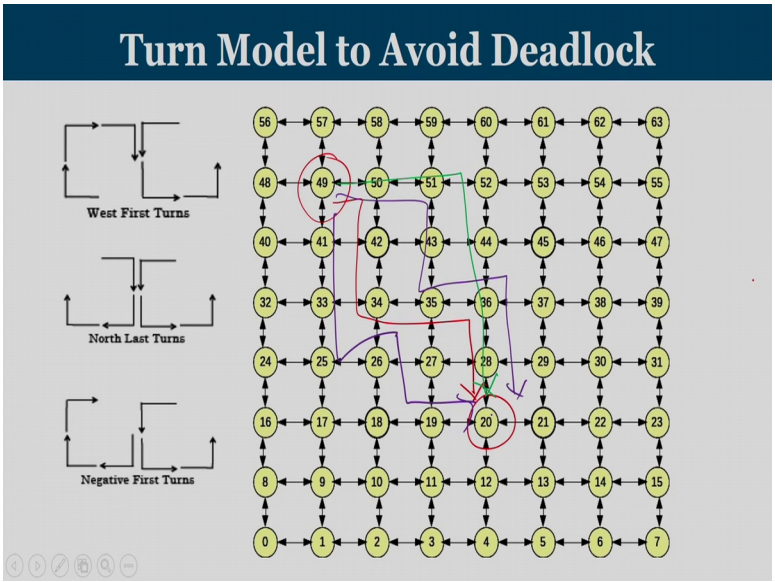


Now, let us try to illustrate some examples for turn model of routing. Consider this mesh network which consists of 8 by 8 routers, total of 63 routers organized as an 8 by 8 mesh. We know that in West first turn these are the turns permitted and North last turns these are the turns permitted and negative first turns these are the turns that are allowed.

Similar to West first turn we can also define East first turn, North first turn and South first turn and similar to North last turn we can define South last turn, East last turn and West last turn.

What are we trying to do let us now consider an illustrative example, which will help us to understand the flow. Let us try to find a packet has to move from 37 and the destination is going to be 18. Let us first employee West first turn.

So, West first turn means if at all you wanted to travel to West you have to travel West right from the beginning. So, if the destination is towards the West of the source tile then take West beginning itself. So, you take one West, second West, third West and then you take South turns to reach 18.

Let us consider one more example where our source router is 37, let say 54 is the destination and I am employing West first turn.

So, the rule West first turn says that if at all you wanted to take a West turn that has to happen in the beginning. Now in this case 54 is the destination, and 37 is the source.

Under this scenario since the destination is already on the East side there is no need to travel towards West.

So, a packet from 37 when it moves to 54 since there is no Westward movement now you can take any path. So, in this case you can take a path like this 45, 53 and then I can reach 54 or it can be 37, 38, 46, 54 or it can be 37, 45, 46, 54. So, all these are allowed, in all these cases we make sure that the 2 prohibited turns in West first turn is not taken. So, whenever the destination is on the East side of the source, West first turn gives a lot of flexibility.

Now, let us try to understand another category of turn that is called North last turn. Consider 20, from 20 I wanted to go to 49. If it is North last then this is the only path because once I take North no more turns are allowed.

If it is from 49 back to 20 by North last routing since I am no longer taking North turns, there is absolutely no restriction for me. This can be one path or you can take another path this is also North last routing because North turn I am not taking. So, there is no question of first and last third one can be I can take like this. I can have various multiple options that is available.

So, North last turns means if at all you are taking North turn it should be taken only at the end. This is an illustrative example. Let us move to the another category of routing which is known as adaptive odd even turn routing.

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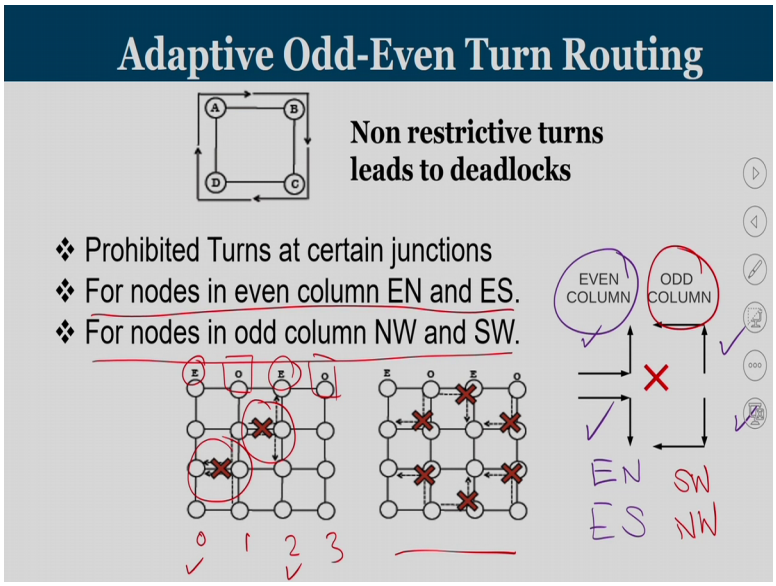


So, in odd even turned routing is we are restricting certain turns at certain positions. When it comes to turn model we tell that this particular turn is allowed only in the beginning or only at the end that make it slightly restrictive. So, odd even routing is another category, where the routing intelligence which is embedded on the router is clearly specifying under which all columns certain turns are allowed, certain turns are not allowed.

So, in all the even columns these 2 turns are not allowed and in the all odd columns these 2 turns are not allowed. So, a packet that is moving in the East direction cannot take a North, a packet that is moving in the East cannot take a South when it comes to even column. Similarly, a packet that is travelling to South cannot take a West similarly, a packet travelling to North cannot take a West when it comes to odd column.

So, for nodes in even column East North and East South is prohibited, for nodes in odd columns North West and South West is prohibited, this is exactly it works. Consider a 4 by 4 mesh where the column numbers are 0, 1, 2 and 3. So, 0 and 2 are even columns, 1 and 3 are odd columns.

So, in even columns these turns are prohibited, in odd columns these turns are prohibited. Similarly, this is also the way how we can try to understand.

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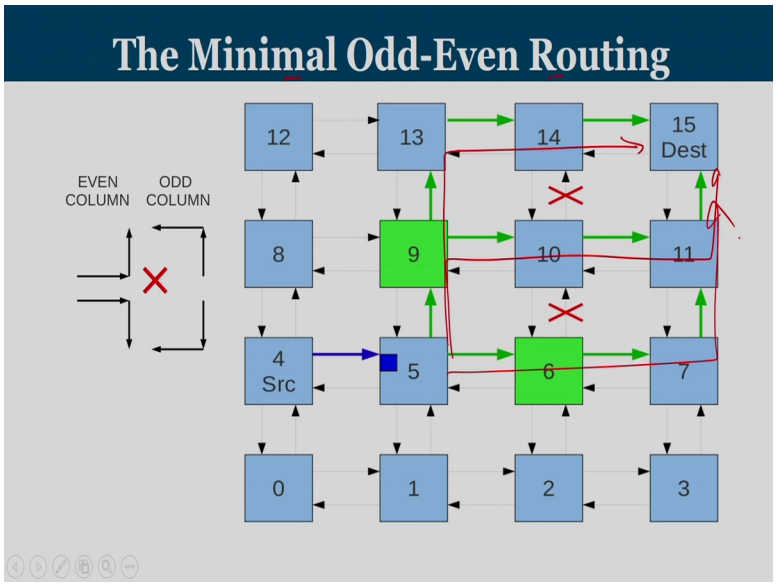


So, there is one more illustrative example so, these are the turns that are prohibited in even and odd columns. Consider this 4 by 4 mesh with 0 to 15 routers, consider a packet that is starting from 4 now it is reached 5 destination is 15. So, 5 is the current router, 15 is the destination, from 5 to reach 15 how many possibilities are there? So, when I wanted to reach 15, I can take 6 or I can take 9, there is no problem at all, that is why 6 and 9 are potential neighbors.

Now, if I reach 6 then I am in the even column so, this is the column numbers. First column is even zeroth column, first column, second column and third column. So, zeroth column and second column are essentially in even numbers at even column this turn is not allowed. So, even though 15 comes in a quadrant at 6 this turn is not allowed.

So, when a packet reaches 6 destined for 15 it can go only to 7 it cannot go to 10. So, wherever you see green color, these are the potential path that is particular packet can take from 5 to reach 15. So, it can take this path, it can take this path or it can take this path, 3 possible paths are there for this packet.

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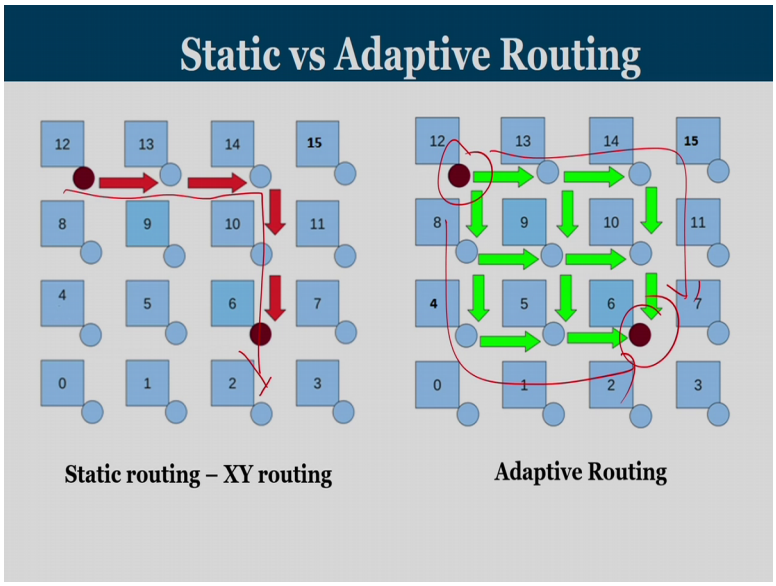


So, we have learned about what is static routing where the packets start from 12, 13, 14 take X direction and then it moves in Y direction. When it come to adaptive routing a packet from 12 in order to reach 6 can explore the adaptivity of the network, all these green paths are there. So, when you explore adaptive routing we have to make sure that it is free from deadlock.

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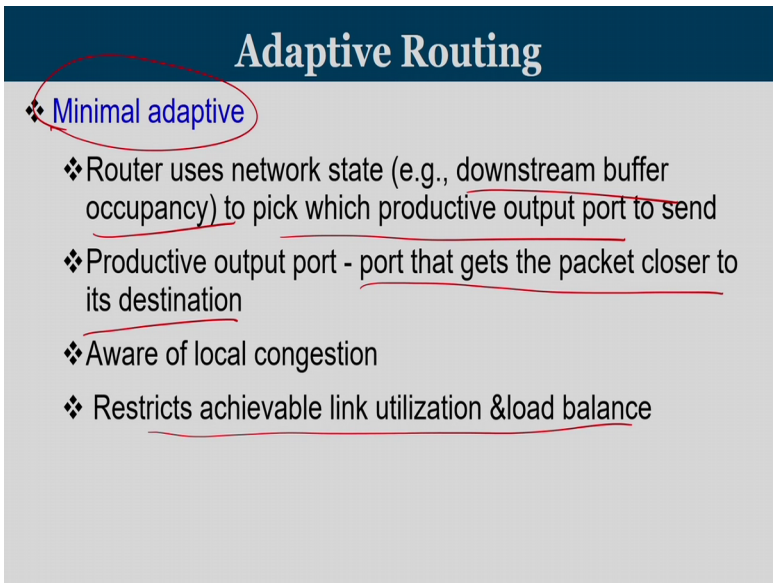


So, adaptive routing as of 2 types, one is called minimally adaptive. So, in minimally adaptive the router uses network state such that I will consult about what is the status of

the downstream router. When we say downstream router the packet where it is currently now it is called upstream, the next router is called downstream.

So, since I wanted to reach destination I consult my potential neighbors through which the packet can go and from the neighbors collect some feedback. It can be in terms of buffer occupancy that is a normal one how many buffers are free and which that neighbor, which has more number of free buffers that is the one that we assume of to be less congested.

And we have to choose the productive output port to send. Now what do you mean by product output port? A port that takes the packet closer to destination is called productive. So, when we work on minimal adaptive from among the productive port look at what are the downstream routers collect their feedback and pick up a call.

So, we are always aware about the local congestion in the productive direction. But, it restricts achievable link utilization and load balance. Since, sometimes the non minimal path may also be more cost effective, but when I am working for minimal adaptive it is giving me some kind of a restriction such that I cannot work with the packets.

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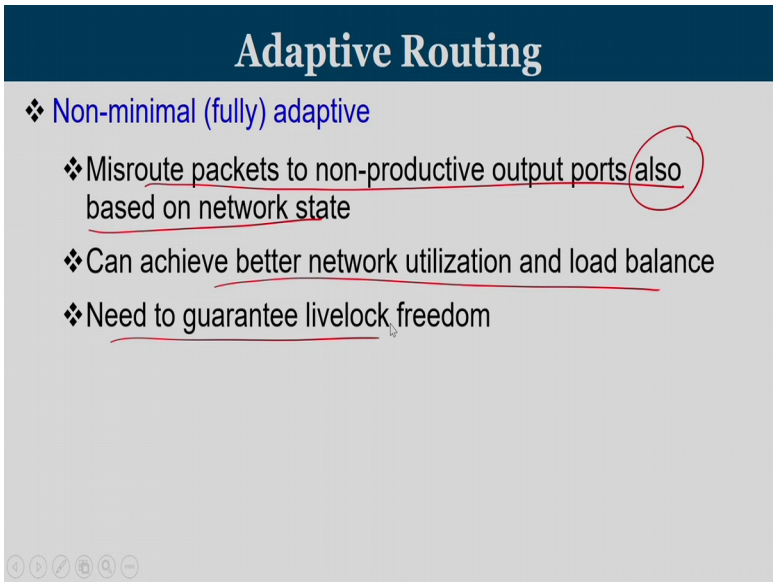


The second category is called non minimal or fully adaptive routing. So, misroute packets to non productive output port also its not compulsory also based on network state, here also you consult the downstream routers in a non minimal scenario. So, some

of the ports may take you closer to destination, some ports may take you away from destination. In both this cases we can actually look into the scenario. Can achieve better network utilization and load balance, we need to guarantee the livelock freedom.

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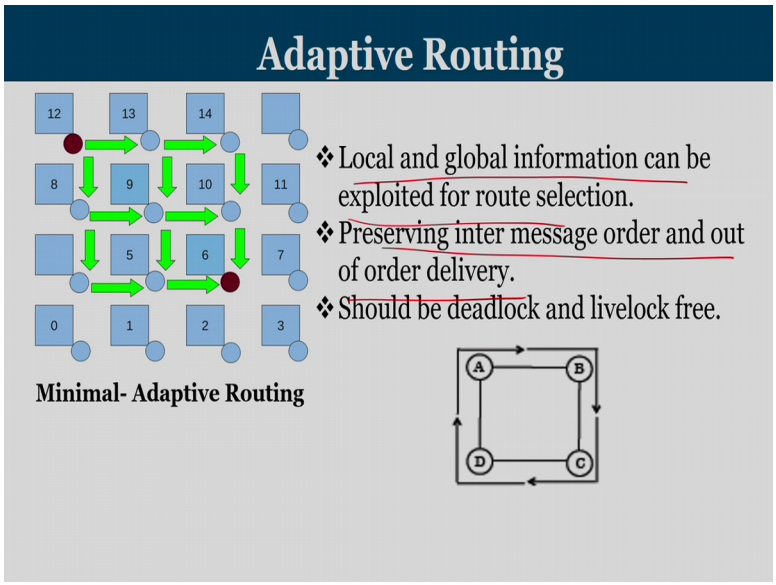


So, what is basically adaptive routing? You have minimal-adaptive routing where local and global information are exploited for selecting a route. Now, when the packets from one tile to another are travelling through different routes, various packets that form a message may be reaching the destination out of order, then all packets are move in same path, we make sure that it will reach in the same order as that of transmission.

When certain packets take a different route by looking into adaptivity then some packets may reach early, some packets may be reaching slightly delayed leading to out of order receipt of packets, this has to be handled.

So, preserving inter message order and out of order delivery is another design challenge in adaptive routing. And whenever we go for adaptive routing it should be deadlock and livelock free.

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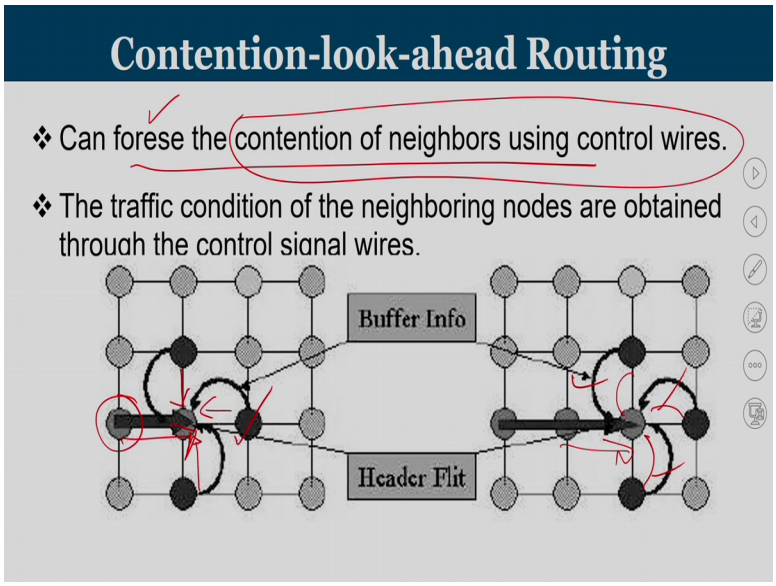


We will try to understand what do you mean by contention look ahead routing. So, contention look ahead routing means it is a component of adaptive routing. When we go for adaptive routing we have many possible output ports that we can take to reach the destination. From among this many possible neighbors potential neighbors can we forese the contention that is available in this neighbors?

And if so, try to collect them it can forese contention of neighbors, for that we are using dedicated control wires. The traffic condition of the neighboring nodes are obtained through specific control channels.

So, normal data move from one tile to another which is called the flit channel. It is through the flit channel may be 128 bit flit channel or 256 bit flit channel that is the channel through which the data flows. To reverse direction we have a control channel which will tell some vital information about buffer availability, congestion statistics or any other parameter that will help us in improving the scenario.

So, you have buffer information so, when you are here you are going to reach the next router. So, once you are in next router try to get feedback from all the potential neighbors and then take a call.

Now, in this case let us assume this particular router is been chosen. So, the packet moves forward there also we are trying to collect feedback. So, what we are trying to so,

is we can forese the contention of neighbors using control wires. So, these are all control wires, the buffer information is been exchanged from one router to another.

So, that completes our days discussion we are just stop going for a quick summary of what we had today. We have understood that network on chip is the future communication framework for tiled chip multi core processors. Under this context we are trying to understand what topology was in our last lecture, how the nodes are been connected, in ring fashion, in mesh fashion, in taurus fashion and in tree fashion.

So, once you picks up the topology the next important thing that we have to understand is a packet can to move from one tile to another. And this movement happens across multiple intermediate routers. And we know that in a mesh connection, which is most popular topology a router is connected to 4 neighbors.

So, these packets upon reaching a router we have to take a decision should a packet be forwarded to North, South, East, West or to the local port. And that decision is essentially called routing; routing can be deterministic where from source to destination you have a prefix the route. It can be oblivious means you take one among the many available routes or it can be adaptive. You take the best route based upon the dynamic traffic conditions.

The second category of classification is source routing versus node routing. In source routing the complete route is embedded on the packet header and that is done with the help of tables that are located at each of the router table management is an overhead.

The other one is called node routing where the destination address information is extracted from the router and then that is going to be used. The third category is called minimal versus non minimal routing. In minimal routing we always make sure that the packet is moving one step closer to destination and a non minimality we may take non productive ports as well.

So, fully adaptive non minimal routing means we can sometimes take non minimal route that may be less congested path and that will take you closer to the destination. So, with this we come to the end of the routing techniques over the next few lectures we will try to understand what is a router micro architecture and how packet are easily moving from one router to another.

Thank you.