Multicore Computer architecture - Storage and Interconnects
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Lecture – 26
Tutorial 5
Concept in Network on Chip

Welcome to the tutorial on the topic Network on Chip. So, today we will be having a couple of problems that we will discuss on how to work with design aspect in terms of network on chips.

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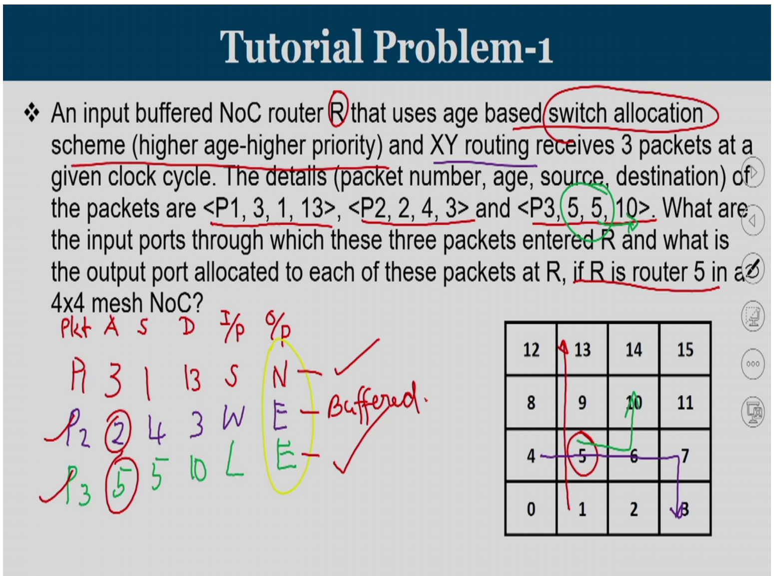

So, consider the first problem and input buffer NoC router R that uses aged based switch allocation scheme, and XY routing receives 3 packet at a given clock cycle. The details are actually given in this. So, there are 3 packets packet P 1 who was an age of 3 and in starting from a router number 1 to router number 13; P 2’s age is 2 from 4 to 3 and P 3 age is 5 which is coming from 5 to 10. What are the input ports through which these packets entered R? R is a router that we talked about and what is the output port allocated to each of these packets at R? If R is router 5 in a 4 by 4 mesh NoC.

So, we will consider what is a 4 by 4 mesh NoC; this is what we see and our point of interest is R is router number 5. So, this is the particular router what we are discussing and we are getting 3 packets P 1 P 2 and P 3. So, we will find out what is the source, what is the destination, what is the input port and what is the output port that each of these packets want and this is the age of that and this is the packet. So, we have packet P 1 it this age is 3 and it is coming from 1 it is going to 13. So, this packet is from 1 it is going all the way to 13 that is a direction of these packets. So, with respect to 5 this particular packet arrives through the south input port and it will shout go to north output port.

So, this is what we see when we have the first packet P 1 if source is 1, its destination is 13 this particular packet with respect to 5 packet from 1 to 13 is coming through the south input port of 5. So, that is what we have written P 1, age is 3 source is one destination is 13 and it is arrive through the south input port. Now let us try to find out what happens in packet P 2; packet P 2 its age is 2 source is 4 and destination is 3.

So, a packet from 4 to 3 will be typically travelling in this direction. So, in this with respect to 5 packet 4 arrives through the west input port and it wanted to go through the east output port, that is the direction since we follow XY routing. Now let us look into what happens to the third packet the third packet is P 3. So, packet P 3 its age is 5 and its travelling from 5 to 10. So, with respect to; so 5 is the current router and we tell that there is a packet which is travelling from 5 towards 10 meaning it is a locally injected packet and this packet will be travelling like this. So, a newly created packet from router number 5 so, it is coming through the local input port and that also wanted to go to east.

So, this is a scenario we have 3 packets packet P 1 looking for the north, packet P 2 looking for the east and packet P 3 that is also looking for the east. So, since P 1 is the only one that is looking for the north output port, P 1 will be granted. But whereas, we could see P 2 and P 3 are the two packets, which are competing for the east that is the case where you have the switch allocation strategy going to play into the picture.

So, switch allocation strategy says that higher age higher the priority. So, when you have two packets here you have packet P 2 as well as packet P 3 both are looking for the east output port at the same time, and to resolve the conflict we look into the age factor. The age of P 2 is two and the age of P 3 is 5.

So, P 3 is the winner. So, P 3 is going to get the output port, whereas P 2 is going to be buffered. So, this is the strategy by which this works. So, in this particular problem we are trying to understand there are 3 packets. These 3 packets are going to arrive on a router the source and destination addresses of the packet is mentioned, the age of the packet is also mentioned you are ask to find out through which input port it comes. So, with respect to where is a source and where is a current router, you will get a field first packet is from one. So, one is on this south side of 5. So, the packet will arrive through the south input port second packet is from 4 to 3 4 is on the west side of 5.

So, that is why the input port is west in the third packet is starting from 5. So, it comes through the local input port. So, that is the way how we deal with our problems like this.

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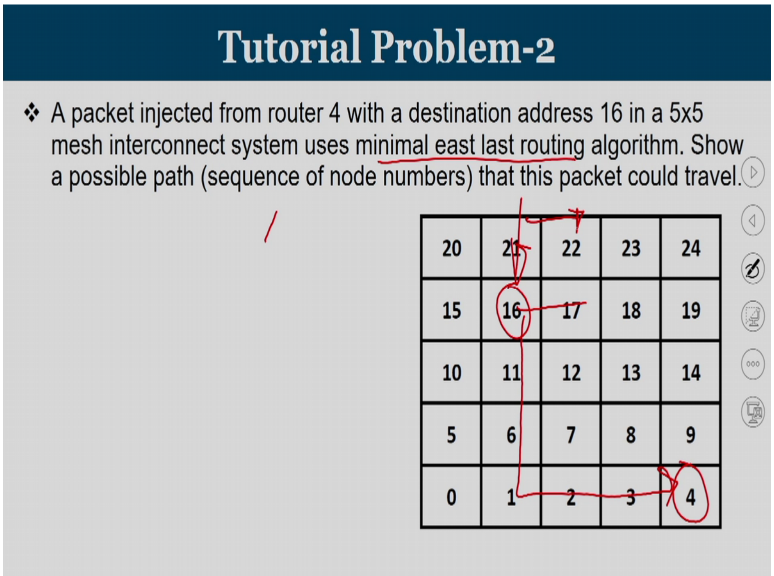

Now, let us move on to the next to problem; a packet injected from router 4 with the destination address 16 in a 5 by 5 mesh interconnect system, uses minimal east last a routing algorithm. Show a possible paths that sequence of nodes that this packet could travel.

So, there are two aspects first is we know we should know that this is a 5 by 5 network, and we are following east last routing algorithm. So, let us try a 5 by 5 network what do you see here is a 5 by 5 network, and always an NoC related problems the numbering starts from bottom left to top right. So, 0 is at bottom left coast all the way to 4, then 5 starts in the neuro like that 24 is on the top right corner. Now what we are talking about is a packet is starting from router number 4, that is a source and the destination address is router number 16. So, a packet from 4 to 16 is what they have to go.

Now, show a possible path, where the peculiarities is we are following east last routing. The rule of east last routing is if we wanted to travel towards the east direction, then we should travel at the last all other turns movement towards west movement towards north, and the movement towards south should be done before. Once you take an east toward the turn, then no other turns are allowed.

So, we can know that the destination 16 is relatively on the west side of the source router 4. Your packet is traveling from 4 to 16 when the destination is towards the west, then there is no east ward movement that is required and we are following minimal east last routing and every hope we have to make sure that we are becoming one step closer to the destination. So, in that is the case like when we are travelling one step closer to the destination, then there is no need to travel towards east because your destination is to the west of the source.

So, we can take any path. So, one touch such path could be to travel a completely in the north direction and then you take a west ward the turn, another possibility can be you can go like this, and the third possibility can be you can take is exact motion like this that is another possibility then you have yet another possibility like this, and you can even try this. So, there access many paths from 4 to reach 16, but this whole problem will take a different shape had the question been asked like let us say the packets start from 16 and moving all the way to 4.

So, how are you going to tackle with that the case? Now you assume that the source is 4 and destination sorry resource is 16 and destination is 4. So, the packets should start from 16 and go to 4 and minimal east last. So, since here you have travelled to east and that east last travelling should be there. So, the only possibility is you travel like that and then you take east, no other turn is allowed because if you take any other turns something like this you are already travelling to east.

So, then you cannot take anymore turn. So, if we move from the column of the source towards the right side; that is towards east ward side then there are no more movements that are allowed.

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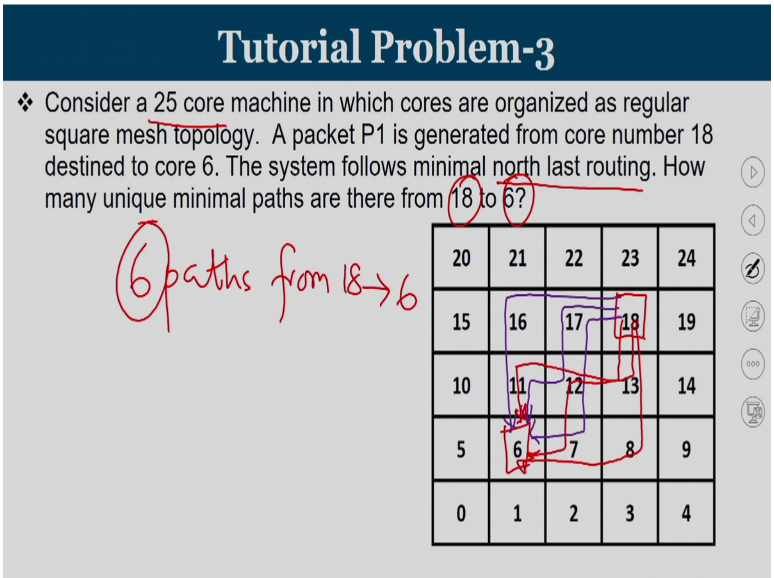

Let us try to go to the next problem; considerate 25 core machine in which cores are organized is rectangular square mesh topology. A packet P 1 generated from core number 18 destined to core 6. System follows minimal north last routing. How many unique paths are there from 18 to 6? So, in the previous question we have seen there are many different paths.

Now, in this question a different set of routing is given we are following north last routing and the packet is from 18 to 6. So, this is also a 5 by 5 network because a 25 core machine organized as a 5 by 5 mesh network. Packet is traveling from 18 to 6 and the routing that we have to follow is minimal north last routing.

So, we have to understand that the destination is on south side of the source; source is 18 destination s6. So, naturally you have to travel towards outward direction, and the routing that is mentioned is north last routing. So, there is no need to travel towards the north direction. So, in this context what are we going to do is, if at all we have to travel to north then that should be travel at the end.

So, since our destination is on south of the source router, there is no restriction that apply because there now where we are travelling to north. And in the case of north last routing only there is restriction towards travelling in the north directions. So, we have many path that exists let us try to find out the first path is from 18 16 e11. So, 18 17 16 11 and 6 that is path number 1; second path can be 18 17 12 116 that is path number 2 third path can be 18 17 12 7 and 6.

Now, the fourth path is let us say we use a different colour to represent, now 18 you go to 13 then to 12 then to 11 and then you come to 6. To fifth path is 18 13 12 7 and 6 and the sixth path is 18 13 8 7 and 6. So, we have total of 6 paths 6 unique paths from 18 to 6. So, we have to see that since there is no route restriction, there are many adaptive routes that is available and we could surely explore path diversity.

So, 18 17 16 11 and 6 that is called and X Y routing; then we have a perfect YX routing 18 13 8 7 and 6 that is a second one and then we have a couple of zigzag routing, there are 4 zigzag routing which will take the packet from 18 to 6. So, the question is how many unique paths are there? We have 6 unique paths are there while travelling from router number 18 to router number 6.

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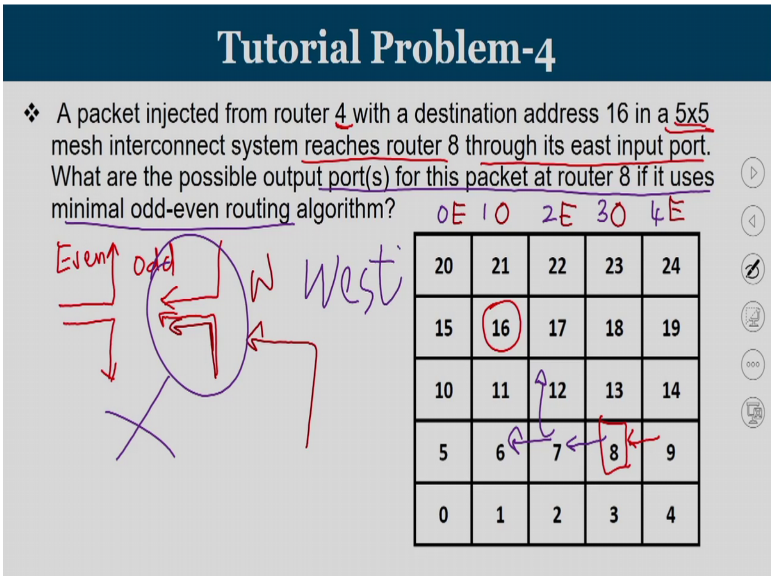

Let us move on to the fourth problem; a packet injected from router 4 with destination address 16 in a 5 by 5 mesh interconnects system, reaches router 8 to its east input port what they are the possible output ports for this packet at router 8 if it uses minimal odd even routing.

So, this is a question that deals with odd even routing, here also we are going to work with a 5 by 5 network. So, we have a 25 core machine let us say 5 by 5 mesh network and the packet is moving from router number 4 it is going to 16. So, destination is 16 and the packet from router number 4 to router number 16 is currently at router number 8. So, this is the router what we are talking about and let us say the packet is coming from this direction why it is coming through east input port. So, with respect to 8 the east neighbour is 9. So, packet is coming from 4 through 9 it reached 8. In the question it is mentioned that packet is coming from 4 and it reaches 8 through its east input port.

So, if this is the scenario how we are going from 8 to 16 what are the possible output ports for this packet? We are following odd even routing and odd even restriction is in even columns, east north and east south are not allowed in the case of even columns; and in the case of odd columns these are the two turns that are prohibited. So, if we prohibited these two category of turns these turns are not allowed in the case of. So, when you have even columns moving towards east direction and then bending 90 degree towards north and moving towards east and bending to south is not allowed.

Similarly for the case of odd columns traveling towards south and moving to west and travelling towards north and moving to west these two are actually prohibited. Let us try to understand this is column number 0, column number 1, column number 2, column number 3 and column number 4 and when we try to represent them using odd and even the first one is an even, column then we had odd column we have an even column and then we have an odd column and then the last one is an even column.

Now, what it tells we are now currently in the odd column; in an odd column we have to understand that this turn is not allowed. So, if the packet is moving anywhere towards the north direction, to reach 16 it has to travel towards west. Somewhere in 13 or somewhere in 18 it has to take a west travelling on north direction shifting towards west is prohibited. So, these turns will not be permitted in the normal case.

So, we have to find out some other route. That means, a turn towards north direction on 8 is not allowed because of the fact that if you take a north turned there are some point of time we may how to travel towards west with is prohibited. So, the only possible way this packet can do is from eighth it can travel only towards westward direction. In west it can go up or it can go straight that is not at all a problem the only problem is we have to think about the odd column by direction.

So, what are the possible output ports for this particular packet at router 8? If it uses minimal odd even routing is, the only permitted output port is west. Because, since we use minimal routing we may use north or we may use west. But if you take a north turn at some point of time we may how to travel towards west because 16 is relatively to the west side of a router 8.

Since router 8 is located at an odd column if we travel towards north direction a further turn towards west is prohibited. So, at 8 north is not allowed then the only possibilities travel towards west. So, this particular question the answer is west is the output port.

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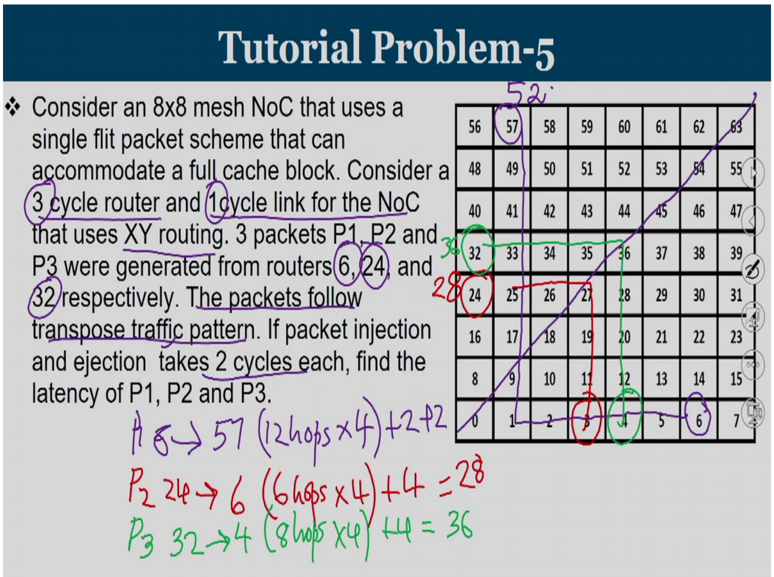

Let us now look into the next problem. So, here we are moving into a larger NoC consider an 8 by 8 NoC that uses single flit packet scheme, that can accommodate a full cache block consider 3 cycle router and one cycle link for the NoC that uses XY routing.

So, the important information is it take 3 cycle for a packet inside the router and its a one cycle for this packet to travel through a link and the NoC uses XY routing. So, we are talking about 3 packets P 1 P 2 and P 3 were generated from router 6 router 24 and router 32 respectively. So, P 1 is starting from 6, P 2 is starting from 24 and P 3 is starting from 32. The packets follow transpose traffic pattern. So, in on our previous examples it was mentioned from where the packet is starting, and to where the packet is going that is the source address and the destination address is given in this question.

But in this particular question it is mentioned that packet will start from 6 24 and 32, but the destination address is not mentioned. It is this information that these packet follow a transpose pattern is an information to find out what are the destinations of these packets. Now if packet injection or ejection takes two cycles each find the latency of P 1 P 2 and P 3. So, consider an 8 by 8 mesh network; let us take the first packet the packet is from 6. So, this is this source router.

Now, we how to find out where this packet is travelling; so for packet P 1 it is travelling from 6 and it is going to. We have to find out the destination using the data given its transpose traffic pattern. The meaning of transpose pattern is, when a packet is moving from row i and column j is destination will be row j and column i. So, a packet from 2 3 row and column coordinates are 2 and 3 will be moving to 3 and 2; 7 1 will be moving to 1 7 3 3 will not be moving anywhere 3 3 will be having the same location.

So, based upon the transport pattern we have to find out this is leading diagonal. So, this is the leading diagonal. So, the elements which are there in the leading diagonal there source and destination is same. Now 6 the source is 6 the transpose of that will be located on 57. So, packet from 6 is sending it to 57, then we how to find out how many hops it will take to reach 57.

It is using XY routing and we have to assume that there is no other contesting packets. So, packet from 6 to reach 57 how many hops are there? So, it is 1 2 3 4 5 6 7 8 9 10 11 12. So, it takes 12 hops from 6 to 57, we have 12 hops and how many cycle I am going to spend in the router? There are 12 hops. So, each of the router we will spend 3 hops and each of the link we are going to spend one cycle.

So, it is 3 cycle in each of the router and one cycle in each of the link. So, total 3 plus one 4 cycle is what we are going to spend on each of the hop. So, we have to cover total of 12 hops. So, 12 into 4 that is the total hoping time and it takes two cycles is for ejection and injection. So, to create a packet it takes two cycle, creation of a packet is called injection and removal of the packet from the router is called ejection.

So, two cycle initially for injection, 48 cycles to travel through the network and two cycle at the ejection. So, we have 12 into 4 plus 2 plus 2 and that makes packets P 1 is going to take 52 cycles. So, I will repeat once again packet P 1 is starting from 6 as for transpose pattern the destination of a packet starting from 6 will be 57, because 57 is located at the transpose position of the position coordinate of 6; 6 and 57 are separated by 12 hops.

So, iI have to pass through 12 routers, I have to go through 12 links each of the router will take 3 cycle each of the link will take one cycle. So, each of the hope will take 3 plus 1, 4 hops. So, 12 into 4 48 is the total hoping time. We have an initial overhead of two cycles for injecting a packet. So, 50 48 plus 2 that will be 50 plus another two more cycle at a ejection. So, the overall value is going to be 52 cycles. Now let us take to the router 24. So, router 24 is the place from which my second packet starts. So, 24 is located at the fourth row 0, 1, 2, 3. So, its third row is there 0, 1, 2, 3. So, 3 is going to be its destination.

So, a packet starting from 24 destination is going to be 3, because they both are at the transpose location. Now from 24 to 3 how many hops are there? Then we will see XY routing 1 2 3 4 5 6. So, packet P 2 is starting from 24 it is travelling to 6, and it is 6 hops and each of the hop will take 4 cycles each plus 4 to in the beginning and to in the end. So, on1 2 3 4 5 6 hops are there. So, that is 6 into 4 that is 24 plus 4 its 28.

So, the second packet latency is going to be 28 cycles. Now the third packet is at 32, and the 4 32 the destination is the under transpose location destination. So, from 32 all packets generator from 32 will be to 4 and this is the hop 1 2 3 4 5 6 7 8. So, we have 8 hops for packet P 3 it is starting from 32 and it is traveling to router number 4 it will take 8 hops, and each hop will take 4 cycles.

So, 8 in the 4 32 plus 4 36; so, it takes 36 cycles for a packet from 32 to reach packet number 4. So, this is a problem where we are given the entire NoC structure, and the traffic pattern is defined as transpose pattern, and using this transpose pattern we have to find out the destinations then you have to find the relative distance between source and destination, the number of hops to reach the destination as per minimal XY routing. So, that will tell you number of hops and you have to find out, how much time it will take to hop one location. And for the router latency is given, each router will take 3 cycle to process the packet and each link will take one cycle to transfer the packets; so its 3 plus 1 4 cycles. So, number of hops into 4 plus packet creation time plus packet ejection time.

So, this is the way how you solve this problem.

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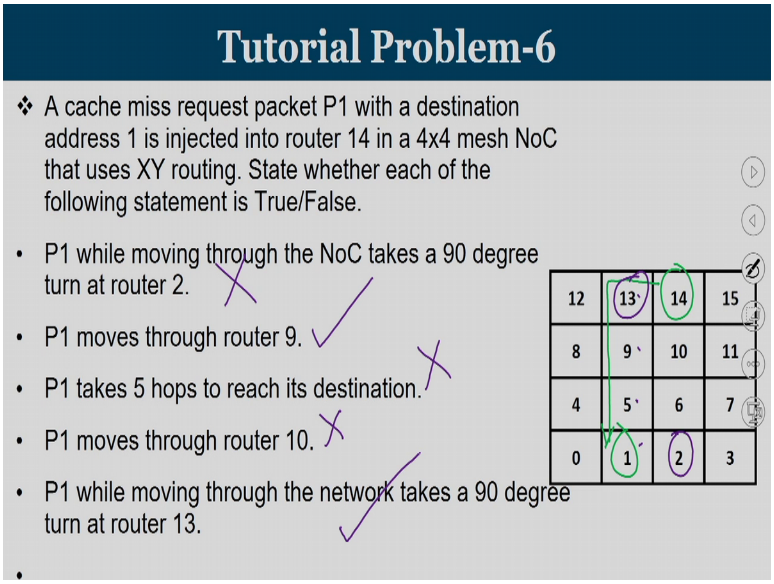

Let us know move into the next tutorial problem; a cache miss request packet P 1 with a destination address 1 is injected into router 14 in a 4 by 4 mesh NoC that uses XY routing. State whether the following statements are true or false. So, here we are talking about a 4 by 4 mesh NoC, and the packet is starting from 14. So, a packet is injected at 14 and that packet is to 1. So, packet is moving from 14 to 1 and it uses XY routing state whether each of the following statement is true or false.

So, a packet from 14 to 1when it is uses XY routing this is the path it is going to take X and Y now considering this let us try to find out P 1 while moving. So, we will take the first statement P 1 while moving through the NoC takes a 90 degree turn at router number 2. So, this is router number 2 it never reaches router number 2. So, the first statement is false first statement mentioned that P 1 while moving through NoC takes a 90 degree turn at router number 2. It is actually take a 90 degree turn at router number 13. So, the answer is wrong.

P 1 moves through router number 9 yes in its path we can see that packet moves from 14 13 9 5 and 1. So, P 1 moves through router number 9 that is true P 1 take 5 hops to reach its destination let us see how many hops it is 1 2 3 and 4 it takes only 4 hops to reach one from 14. So, this is wrong; now P 1 moves through router number 10. So, in its path we can see that we would never move through router number 10. So, that is also wrong. P 1 while moving through the network takes a 90 degree turn at router number 13 yes; in its path we can see it is moving from 14 to 13 and that 13 we are taking a 90 degree turn

So, this statement is also true. So, given this problem we try to write down what is the path this particular packet is taking, and there are certain statements that are given with respect to the routers it is going to visit. The routers at which it is transitioning from x ward moment to y direction moment. So, that is way how we are going to solve this.

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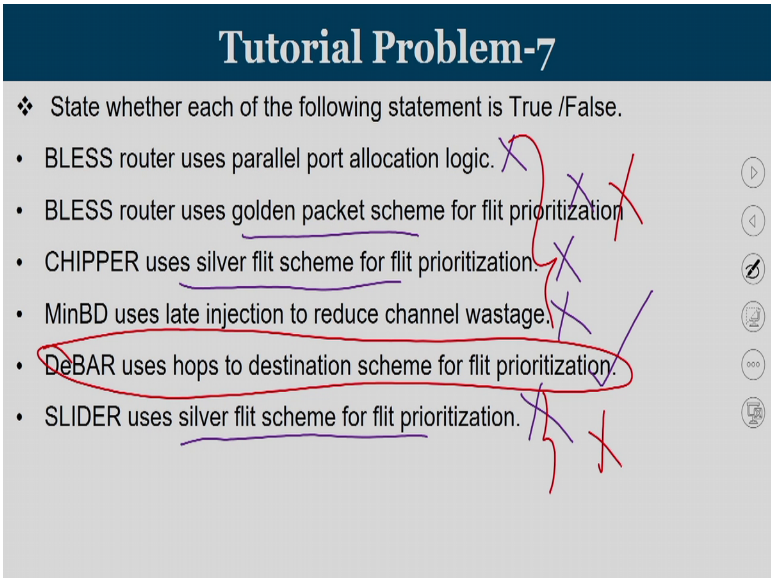

Now, this is a set of statements in tutorial problem number 7, some properties with respect to the energy efficient NoC routers like bufferless deflection routers. And minimally buffer deflection routers are actually given

We have to say whether it is true or false. So, we have two statements with respect to BLESS one statement with respective CHIPPER one with MinBD one with DeBAR and one with slider. So, only if you understand the router pipeline of all these routers then only we can able to solve this kind of statements. This statements essentially check how much deeper you know about the internal working of this Bufferless deflection router.

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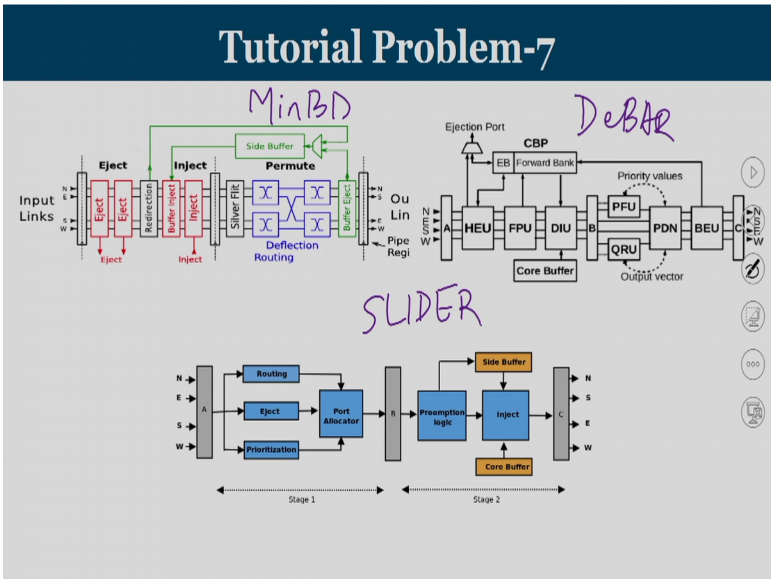

So, before going into that let me tell you this is the mind design what do you see here on this left side and this is DeBAR design and then this is the SLIDER design. So, 3 routers are given. Now the first statement BLESS router uses parallel port allocation logic. BLESS was the very first bufferless router that was proposed and there you are using a sequential port allocation scheme. You look at the age of the flits the highest age flits is been given whatever port it wants. Now only whatever is the balance ports that are available only those can be considered for the next two packet.

So, you take one packet assign the available port then from among a balance port that is only given to the next flit. So, it is a sequential port allocation. So, the statement that BLESS router uses parallel port allocation logic is wrong. Second BLESS router uses golden packet scheme for flit prioritization the priority mechanism of BLESS is based upon age the age of the packet is looked and that highest age packet is never deflected; the golden flit scheme is actually there in CHIPPER not in the case of BLESS

So, the statement BLESS router uses golden packet scheme that is also wrong. Now third one CHIPPER uses silver flit scheme for prioritization. The concept of silver flits scheme is introduced in MinBD router essentially CHIPPER is actually working with the golden packet concept.

So, CHIPPER works with golden packet concept and MinBD works with both golden packet as well as the silver plate. So, the statement CHIPPER uses silver flit scheme for flit prioritization is also wrong. Now third or the fourth statement MinBD uses late injection to reduce channel wastage. Let us go into the diagram of MinBD. So, this is the point of injection of MinBD, and it is not a late injection late injection means i am injecting towards the end of the pipeline.

So, we can see that it is the SLIDER design that performs late injection it is not the MinBD router. So, the statement MinBD uses late injection to reduce channel wastage is the wrong. Now fifth statement DeBAR use hops to destination scheme for flit prioritization, so which is DeBAR and DeBAR has a priority fixing unit, and to mitigate the problems with MinBD which is using the silver flit concept. And golden packet concept which are not ensuring progress because silver flit mechanism will select one of the flit arbitrary random to become the silver. To get rid of that is the DeBAR design, they are finding out a better priority scheme and DeBAR works with hops to destination priority. So, whenever I reaches closer to destination my priority is going to increase

So, hops to destination priority is been used in the case of DeBAR. So, the statement DeBAR uses hops to destination scheme for flit prioritization that is true. And the last statement silver SLIDER uses silver flit scheme for flit prioritization silver flit scheme is basically used by the MinBD design in the case of SLIDER that is actually using hops to destination. So, this is also wrong. So, out of the 6 statements that is given, its only the statement pertaining to DeBAR that is true and all others are actually faults. So, to answer this kind of questions we need to have a basic understanding about how this buffered and side buffered router and bufferless routers are going to work

So, today is tutorial let us try to see what be it summarized.

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In today’s tutorial we were trying to find out the underline concepts of network on chip, given certain problem scenarios there were questions pertaining to what are the path a packet is going to take based upon a routing algorithm, then we have seen about an arbitration process when multiple packets reach the router how are they going to compete each other its flit arbitration process is also mentioned.

Then we have seen about different kind of adaptive routing, east last routing north last routing, and how are the packets moving. And we had a question where we will find out the latency of a packet given the router pipeline and the link latency and then we have seen about few statements and to check whether they are true or false based upon the underline concept of the working of the routers. So, I request you to work with few more problems like this, and this will help you in better understanding the problem domain that is covering the NoC aspect.

So, with this lectures that are already been disposed to you kindly go to the lectures well try to understand the concepts of network on chip and then take up these tutorial problems it will give you a better grip on how to work with this. So, with this we conclude today’s tutorial.

Thank you very much.