VLSI Physical Design with Timing Analysis

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Week 09

Lecture 43

Introduction: Detailed Routing

Welcome to the course on VLSI Physical Design with Timing Analysis. In this lecture, we will discuss about detail routing. So, content of this lecture includes introduction to detail routing, some of the terminology involved in detail routing, then we will go into horizontal and vertical constraints and using those horizontal and vertical constraints, we will create horizontal constraint graph. So, we already discussed about the global routing in our previous lectures, which is concentrating on the coarse grain assignment of routes to the routing regions. So, we have different routing regions and in those routing regions, we have assigned the nets to those routing regions. Now the detail routing does the next step of fine grain assignment of the routes to the routing tracks.

So, this is the final routing stage where all the nets are assigned a metal line and the corresponding via. So, there is another thing is there which is called timing driven routing that is not included here. So, the main objective of the detail routing is assign the basically routing segments to the signal net to a specific routing track. So, you have multiple nets there in a given routing region.

So, here what we are doing, we are assigning those signals which track it will belong, which track it will be assigned. Then once the track is assigned, we need two things, one is the metal layers and the via because there might be a horizontal metal and vertical metal. So, we need via to connect between the horizontal metal and the vertical metal. So, we are assigning the tracks via in the metal layers in a manner consistent with the given global routes of those nets. So, it should also satisfy the constraint imposed by the global routes.

So, we have a constraint given by the global routes that need to also be satisfied when we are doing these assignments. Then here we can see one thing, the layout region is represented by coarse grid consisting of a global routing regions that is also called the 'g cells' or more general routing regions. So, if you can see this figure here. So, these are the blocks B1, B2, B3 and B4 are the blocks and these basically routing regions, these are the routing regions actually. This is one channel, this is basically switch box, this is a switch box.

So, all these routing regions is also called as g cells'. This is also called the 'g cells' or the global routing cells. So, actually the coarse grids actually, it is not fine grids, these are the coarse grids. So, this routing regions consists of two different things what we already discussed, one is the channel and switch box. So, for example, if you can see here, this is a switch box because you have tracks in all the four sides. Like we talk about the square in a road where you have traffic coming from all the sides. So, this is called a switch box and, in our VLSI physical design we call that basically switch box. Then we have channels actually. So, for example, here this one between this one, this one is a channel between these two blocks B3 and B4. So, these channels and the switch box consists of the g cells'.

So, these are the coarse grids, these are not fine grids, these are coarse grids actually. These are coarse grids. Each cell g cell' is orders of magnitude smaller than the entire chip area. So, if you have a bigger chip, these 'g cells' are very smaller in size compared to the complete chip area. What is the advantage of that is that we do two things, one is divide the problem into sub problems and apply parallel algorithms. So, what we are doing here, the first point is we are dividing the problem statement using a divide and conquer framework. Then the second one we can apply parallel algorithms. Why you can apply parallel algorithms? Because all the problems can be solved parallelly because we are solving each of the 'g cells' independently. So, we can exploit the property of divide and conquer and parallel algorithm to efficiently do this the objective of detailed routing. So, your detailed routing runtime can scale linearly with the size of the layout.

All the things are independently happening. So, you can scale the routing runtime which is basically linearly changing with the size of the layout. So, these detailed routing techniques are applied within routing reasons such as channels, switch boxes and the third one is the global routing cells. So, these detailed routing techniques can be applied for all these cases. So, let us take an example how this is happening.

Let us say I have some net N3 is connected to this N3. So, this N3 is connected to N3. So, here whenever this global routing is happening, these nets are connected but the corresponding metal via and tracks is not assigned. But if you go to the detailed routing there will be one thing is track assignment, the second one is the metal layer assignment, then the third one is the what kind of via assignment. So, all the three things should be performed. Now if you can see here for take the example of N3 only that can be applicable for all the things. If you can see here, you have two metal lines. This line is let us say horizontal segment or horizontal metal and this segment is a vertical metal and this one these are called the vias. So, what it is doing is that N3 is routed using two metal segments, horizontal metal which is the solid line and a vertical metal which is a basically the vertical metal is represented by dotted lines and the vias are connected using this square box which connects the horizontal metal with the vertical metal. In this manner all the nets are routed in the phase of detailed routing.

So, these are the vias. Now we have some terminology related to this basically the detailed routing. So, me of the terminologies are important one is called channel routing, one is called switch box routing. Channel routing is a special case of detailed routing. This is a special case of detailed routing where the connection between the terminal pins are routed within the region that has no obstacles.

So, whenever you are doing this routing there is no obstacles. Where the pins are located? The pins are located in opposite side of the channel. Let us say I have a basically a block is there another block is there let us say this is B1 and B2 the pins locations are let us say here let us say A, B, C, D, E then let us say this is E, A, B, C, A for example I am giving example. So, these pins are there in both the sides of the channel opposite sides of the channel basically this opposite sides of the channel and this is called a channel. This is called a channel. So, our problem of detailed routing is how we can connect them such that all the nets are connected through the metals. So, in case of switch box routing this is performed when the pin locations are given four sides of the sides of a fixed size routing regions. So, in this case what happens in the in case of switch box let us say I have a box like the I have a block let us say like this. So, here let us say this is B1 block, this is B2 block, this is B3 block, this is B4 block and this is called your switch box. So, this area is like a square in case of a road traffic so this is called your switch box.

So, here we have routes possible in all four directions. So, you can do the routing in all the four directions in case of switch box routing. So, look into one example here. So, here in this case if you can see this is a channel this area is called a channel and if you can see I have some pins in the top and some pins in the bottom. So, these are my pins in the top, these are my pins in the bottom.

What is happening is called a channel routing. This routing the connection between the basically the pins through the metals is called a channel routing. Similarly, if you can see here you have four blocks are there let us say this is B1, this is B2, this is B3, this is B4. So, then basically this area where we have four side is open for routing, four side is open for routing that is called basically switch box routing. This is vertical channel track and this is a horizontal channel track.

So, this is called switch box routing. Now there is very important and very useful that is called over the cell routing. So, in traditional routing methodology we use two layer means very old times we have two layer channel routing solution. Why this was the only solution available because we do not have multiple metal allowed in case of fabrication.

So, two metals was there. So, over the cell routing is not allowed. So, what is the over the cell routing we will discuss in this slide. If you can see in this figure, the figure 1 let us say this figure 1 and let us say this is figure 2. So, in this case in case of figure 1 you have more routing tracks and less metal layers. So, you have one observation, two metals are used and the second observation is that we have more routing tracks.

More routing tracks means you can see here this is one track, this is second track and this is third track. So, you have three routing tracks. So, here what is the disadvantage? Disadvantage is that it will occupy more area in the silicon. The disadvantage is that it will occupy more area. Now I will go into the second one, this over the cell routing.

Here what is the thing is that I have three layers, one observation is that three metals are used in routing and number of tracks in the channel, the same channel is there. Number of tracks is two routing tracks and if you can see here there is a metal 3 which is used above the blocks. If you can see here there is a routing using this metal which is the metal 3. How it is possible? Because this is possible if you have no blockage of routing for metal 3 in those areas. This cell area whatever the cell area we have we do not have any blockage for the metal 3.

So, here in this area no blockage for metal 3 routing. So, this blockage if it is there then it will not do the routing but if there is no blockage then it will do the routing. So, this concept is called the over the cell routing. If the metal 3 is used inside this block then you cannot do this but if there is no blockage then you can do this and the fabrication process will support the metal 3 metal in the fabrication. So, what is the advantage of this one? The advantage is that it will occupy less channel area because you have two routing tracks. This is one and this is two. This concept can be extended for all other metal layers in the fabrication process.

So, now we will discuss about the horizontal channel. So, in this horizontal channel if you can see you have basically this is one block basically this is block 1 and this side is block 2. I have a channel. So, you have this vertical segment. These are vertical metals and these are the horizontal metals. Let us say this is vertical metals and let us say this red one horizontal metal. Now what is the thing is that it depends upon the channel height and the metal to metal pitch what we discussed in case of global routing. So, here we have three tracks is given to us 1, 2 and 3. So, what are the horizontal tracks here? So, if you can see here we have three horizontal track is here and this top is basically the ID.

So, this top and bottom are vector of net IDs. What it does basically what are the vectors there? So, first the B then the next one is no pin actually then B then C D B C. So, this is the for the top of the channel and this is the bottom of the channel. So, this is A C A B 0 B C. So, this is the bottom of the channel. So, these are the vector of net IDs which corresponds to the pin locations.

Now what is the horizontal constraint? There is a horizontal constraint exists between two nets if their horizontal segments overlap when placed on the same track. Now we can classify the horizontal net into two categories one is horizontally constraint horizontally unconstraint. This is first category and this is the second category. How they differentiate with each other? So, if a horizontal constraint exists between two nets if their horizontal segments overlap when placed on the same track. If you can see here you have a B pin here you have a B pin here you have a C pin here you have a C pin here and this B C these two pins are opposite to each other. So, what is happening is that you cannot use the same track same horizontal track here because they overlap with each other. So, the B C are horizontally constraint so thus they require two different tracks. So, they require two different horizontal tracks.

But if you can see this A net and the B net. So, A and B are horizontally unconstraint so that imply they can use same track. If you can see here the same track is used by this and same track is used by here. So, this is called horizontally unconstraint. Now we have a vertical constraint is there. So, if you can see here I have a pin A and B is there.

Pin B is there and pin A is there. So, A pin should be connected to A pin B pin should be connected to B pin. So, the vertical constraint exists between two nets if they have pins in the same column. If the pins are there in the same column. So, if you can see here this vertically constraint without any conflict. So, here you have two categories there one is called vertically constraint without conflict and if you can see in vertically constraint with a vertical conflict because if you can see here so here case 1 and case 2. So, in case 2 what is happening A B are opposite pins actually in the same column. So, A pin and B pin and B pin and A pin are in opposite pins in the same column. So, in that case you have more horizontal tracks are needed. For example 1, 2 and 3 more horizontal tracks are needed to resolve the routing. So, here between two nets they have pins in the same column.

But in this case you have a vertical constraint is still there but you can solve this problem with basically two tracks 1 and 2. So, this is the vertical constraints. Now we will discuss about how we can draw the horizontal and vertical constraint graph. So, this horizontal and vertical constraint graphs is very useful for detailed routing. So, basically tells about the relative positions of the net in a channel routing instance. So, this relative position of the nets in the channel routing instance can be used to create this horizontal and vertical constraint graph. So, these graphs are basically useful to predict the minimum number of tracks that are required. So, it will basically if we can create this horizontal and vertical constraint graph it will tell how many minimum number of tracks are required to do the detailed routing. It also solves all possible type of routing conflicts.

It also solve all kinds of routing conflicts. So, there was some notations are needed before going to this horizontal constraint graph. So, we have a sub column is there. So, for each column it will contain all the nets that are connected to a pin in the column. So, it will connected to a pin in a column and a pin connection to the both the left and right of the column. So, the pin connection in that column and the pins coming in the left and right side of the column.

So, then you have horizontal segments cannot overlap. The horizontal segment cannot overlap. So, each net in S column must be assigned to different track in the column. So, two horizontal segment cannot overlap. So, if you have a net in S column that must be assigned a dedicated track in the column. So, that is the meaning of that. If you have S column element in S column that should be assigned a dedicated track in the while doing the detailed routing. This S column represents the lower bound means how what is the number of track in that column is determined by the number of elements in that in S column. So, the lower bound of the channel height is given by the maximum cardinality of S column. So, what is the number of element in S column is defined by it will determine the channel height. So, this number of element in S column will determine the height of the channel.

It will be more clear with an example what I will explain in the next slide. So, if you can see here this is my channel and this is the pins and these are the pins in the bottom. Now let us say for the 0, S of 0. So, S of 0 we have one pin A. So, you can write S of A as 1, but it will go away because it is a subset of other S of B.

So, we will discuss. So, first we will see S of B. So, if I have S of B this is basically A, this is B like that we are doing. So, for B for this B basically this B corresponds to this B. So, S of B says that how many pins are there in that column and how many routes are coming from left and right. So, if you can see what are the pins there in that column B and C. This B is one pin I will do in a different color. So, the B is a pin here and this C is a pin here. So, B and C are there in S of B. Now you have one more thing which is coming in the left and right direction. So, if you can see here the pin A is coming in from the left to right. So, this A is also included. So, this one this route is also included in S of B. So, the S of B is ABC and if you can see here S of A is having one element. S of A is having one element. What is that A? Now S of A is a subset of S of B.

So, we can ignore S of A. So, it is explained here. So, if you can see here if there exists a column I and J such that S I is a subset of S J then S I can be ignored. Since it is impose a fewer constraint on the routing solution than S J. So, here why this S of A is not included because it is a subset of S of B. So, that is a point here. Then what you have to do? We have to find those are not subset and for example the S of C is important, S of F is important, S of G is important, S of I is important.

Now we will create a constraint graph, horizontal constraint graph. S of C, F, G and I. So, if you can see the S of C has how many tracks, how many pins in that track. So, if you can see the D should be there definitely, this is a pin in C, E should be there indefinitely. Then how many tracks are going from left to right? So, A, B and C. So, A, B, C are the coming from left to right and C and B are the pins, these are the pins actually, pins in the top and bottom. So, similarly you can see for other you can calculate the S of other pins. So, now you can create that from this information you can define how many number of minimum number of tracks are needed. Maximum can be anything but what is the minimum number of tracks needed? So, it depends upon the maximum cardinality of S of all the pins. So, if you can see here S of C has maximum number of nets. So, you have here number of tracks is basically 5.

So, now we will discuss about how can create the horizontal constraint graph. So, this is very important how can I create a horizontal constraint graph for a channel. So, this is basically SCG of V, E. Whenever I have a graph I have two things, one is vertex and edges. Since vertex is basically the in case of nodes V is the nets of the netlist. So, here I have nets in the basically the nets are A, B, C, D, E, F, G. Those are the nets. So, the number of nodes in this case is basically all the pins or the nets what is there in the top and bottom. So, here A, B, C, D, E, F, G, H. All these are the nets. So, nodes are okay, those are the nets but where the edge should come? The edge will come when there is a basically i, j if the corresponding nets are both elements of the A sub column.

Let us say if you can see A should be connected to B, C, D, E. So, if you can see in A node is connected to B because of this, C because of this, D because of this, then E because of this. So, these are the connections coming from S column. Similarly, you can do it for all other edges in the. Similarly, you can do it from B also. B should also connected to B node should connected to A, C, D, E. C should also connected to A, B, D, E. Like that it will continue. So, by that method after this calculation of this table we can easily create a horizontal constraint graph.

So, in this lecture we discussed about detailed routing and some of the terminologies involved in detailed routing.

Thank you for your attention.