Optimizing the Antenna Area and Separators in Layer Assignment of Multi-Layer Global Routing

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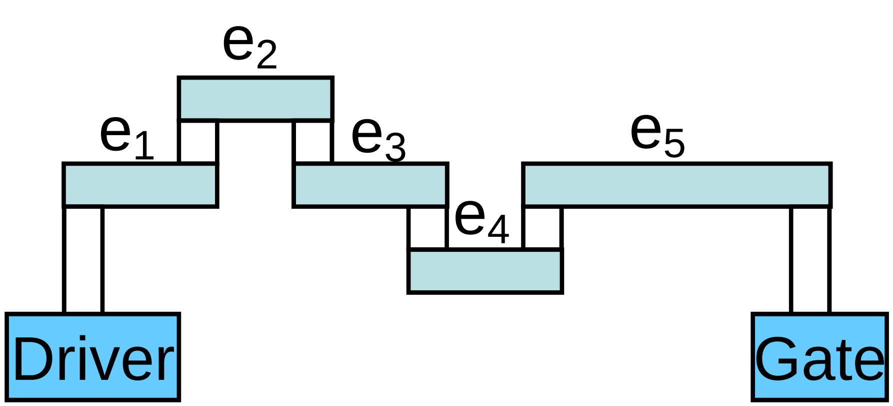
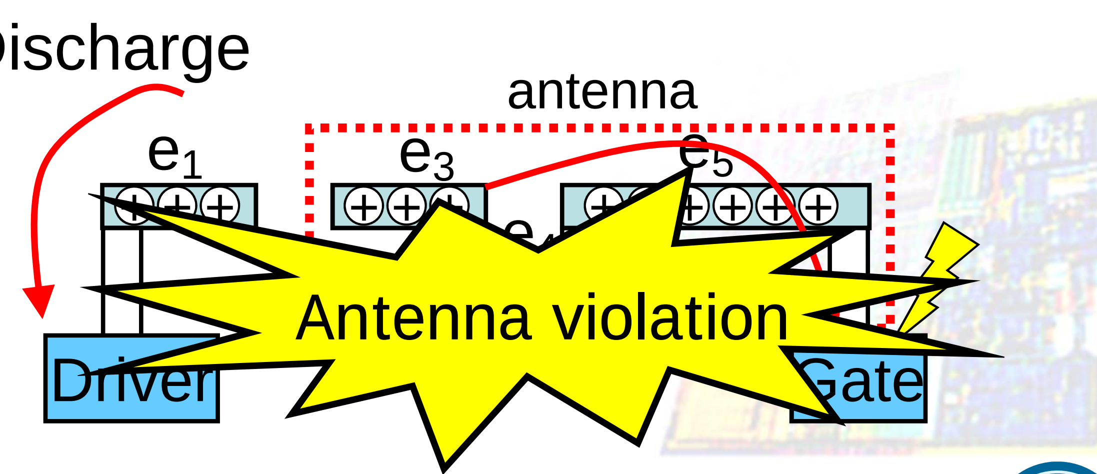
Outline

- Introduction
- Problem Formulation
- Previous works
- Proposed Algorithm
- Experimental Results
- Conclusion

Introduction

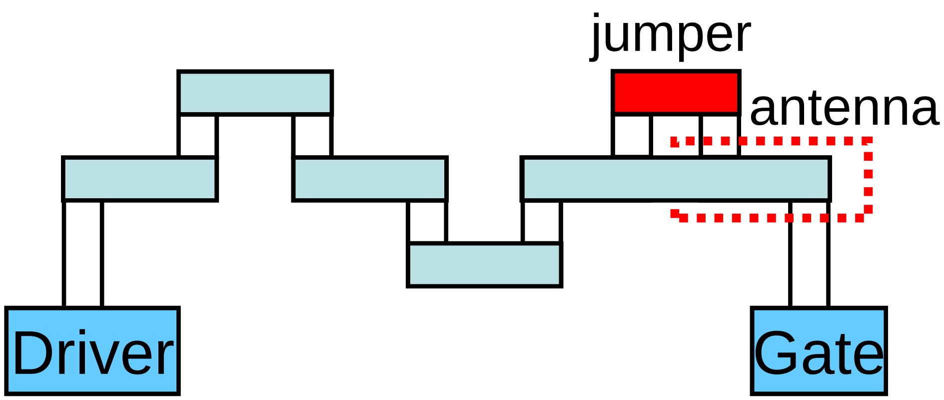
- Metal wires are manufactured layer by layer
  - Wire segments store the charges induced from plasma etching.
- Wire segments may collect the charging current functioning as an antenna.
  - If the collected charges of an antenna exceed a threshold, the gate oxide may be damaged.

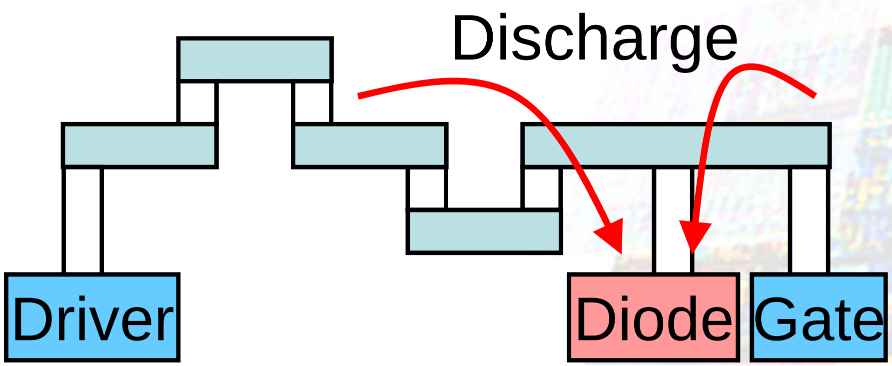




Traditional Solutions for Antenna Effect

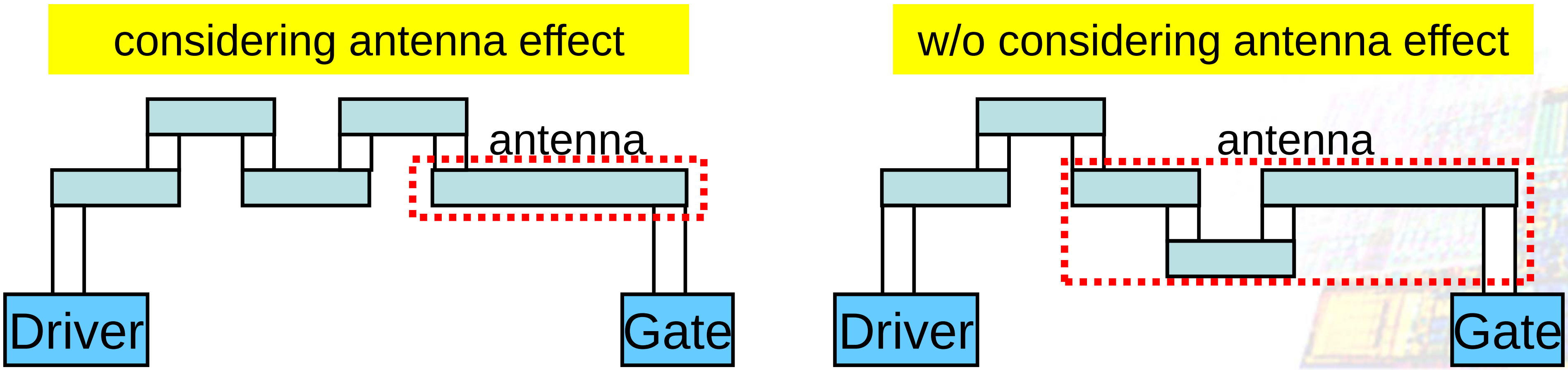
- Jumper Insertion
  - The wire segments with antenna violations are split and then routed to the top-metal layer.
  - Consume additional vias
- Diode Insertion
  - Place diodes near the gates with antenna violations
  - Need extra silicon space to place the diodes





Layer Assignment for Antenna Effect

- The jumper and diode insertion approaches can effectively fix antenna violations during detailed routing or post optimization stages.
- The costs of additional vias and inserted diodes would degrade the circuit performance and manufacturing yield.
- Considering the antenna effect during early stages can prevent antenna violations at a lower cost.



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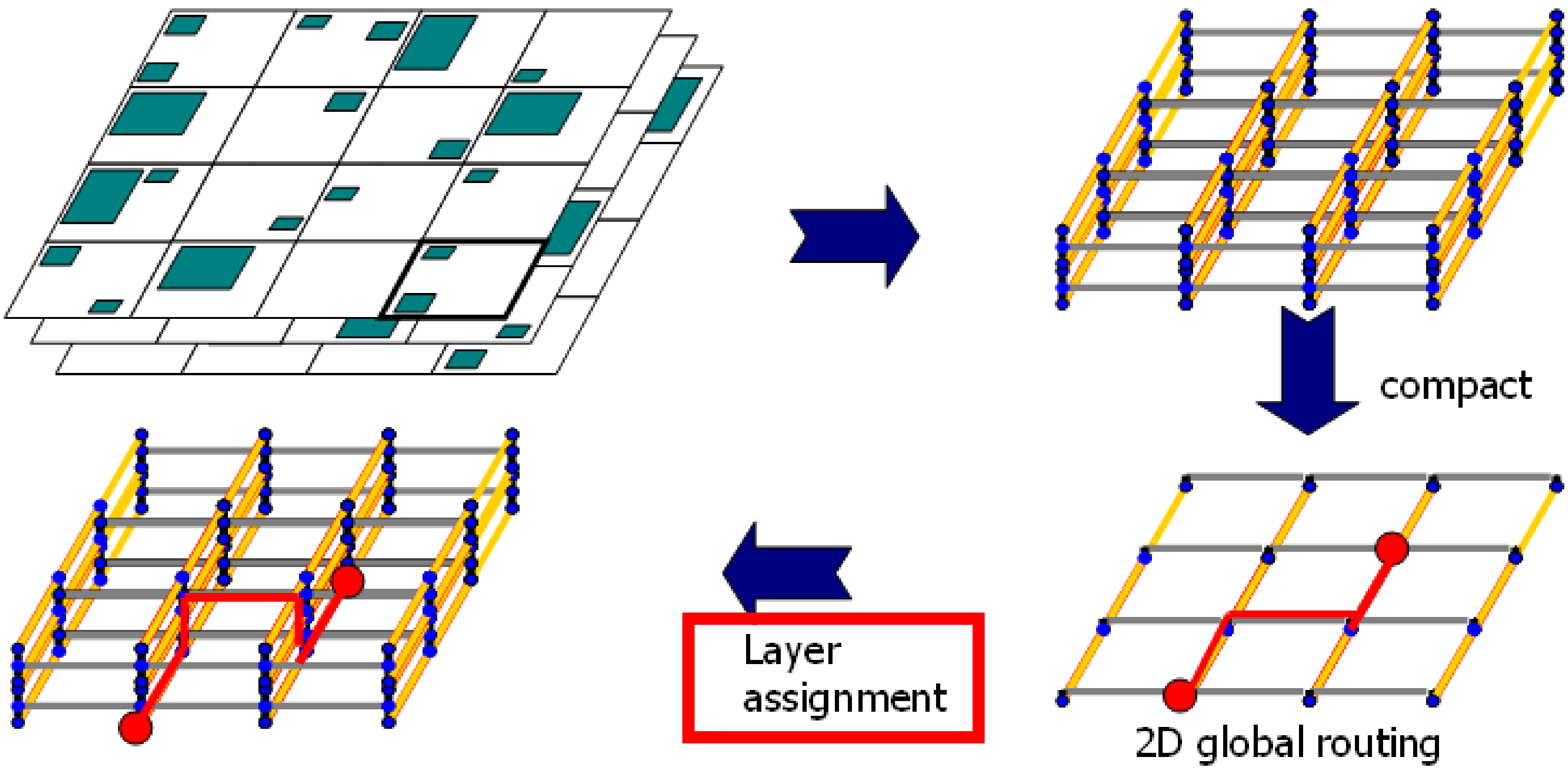
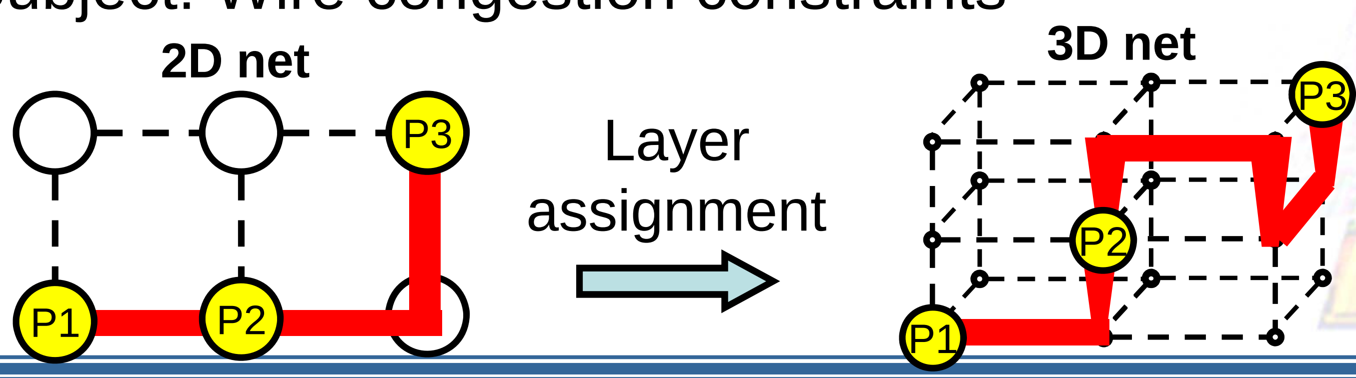
Problem Formulation

- This work addresses the antenna effect in the layer assignment stage of global routing.
- Global Routing Flow :



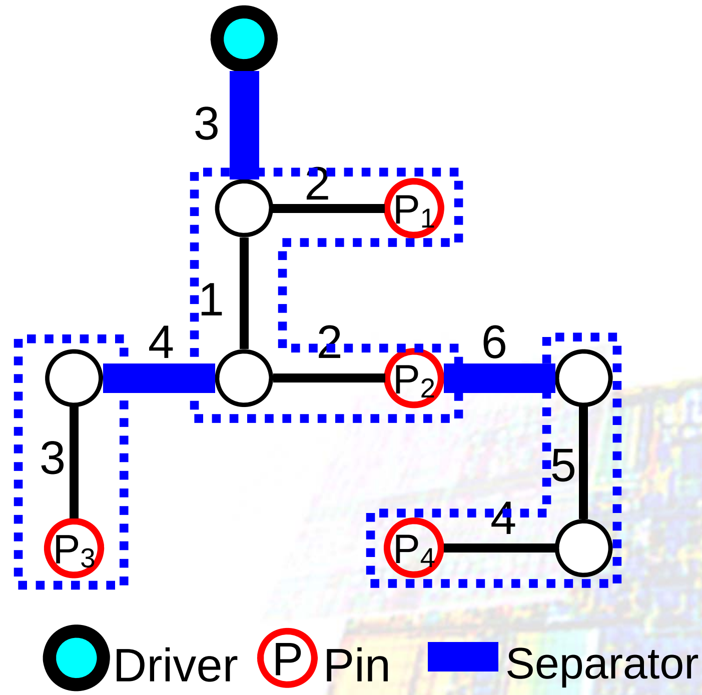
Layer Assignment Problem

- Layer Assignment for Via Count Minimization
  - Minimize : Vias
  - Subject: Wire congestion constraints
    - The total overflow does not increase after layer assignment
    - Overflows are averagely distributed to each layer
- Antenna avoidance layer assignment
  - Minimize : The number of nets with antenna violations, vias
  - Subject: Wire congestion constraints



Traditional Antenna Rule

- A wire segment *e* is regarded as a separator if *e* is on the top layer of a routing path from a pin to the driver.
- Separators partition a net into several sub-nets, each sub net functions as an antenna.
- If the antenna ratio of an antenna in a net exceeds a threshold A_{max}, we can regard this net to have antenna violations.



[1] T.-H. Lee and T.-C. Wang, "Simultaneous antenna avoidance and via optimization in layer assignment of multi-layer global routing," ICCAD'10

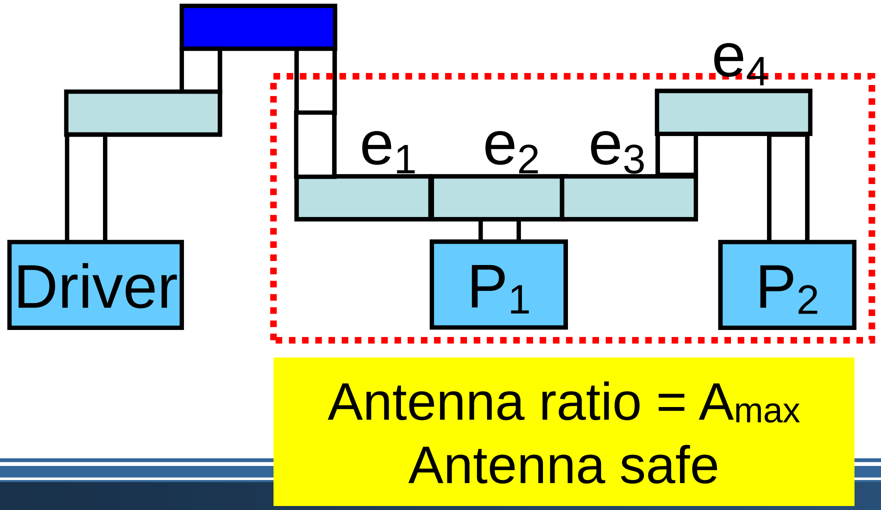
Antenna Rule used in This Work

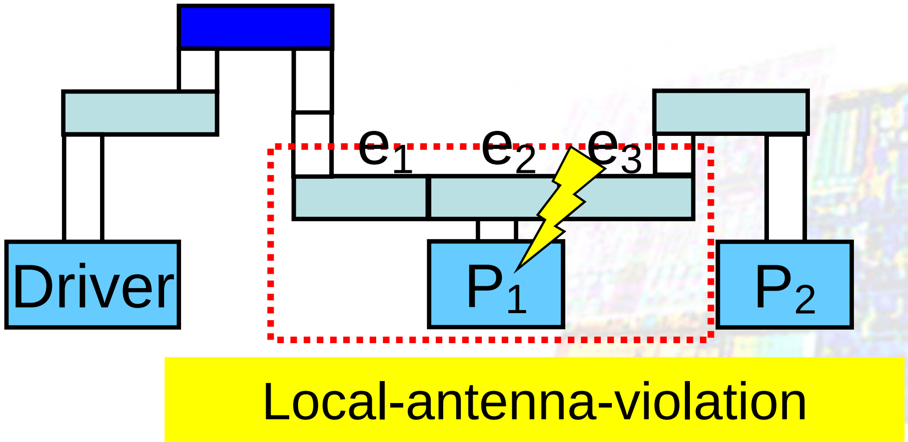
- [1] uses the following antenna model to calculate the antenna ratio.

$$\text{antenna ratio} = \frac{\text{total exposed antenna area}}{\text{gate number} \times \text{the oxide area per gate}}$$

- In some circumstances, layer assignment results obey this antenna rule, gate damage still occurs.
- To avoid local-antenna-violations, this work adopts the following strict antenna model,

$$\text{antenna ratio} = \frac{\text{total exposed antenna area}}{\text{the oxide area per gate}}$$





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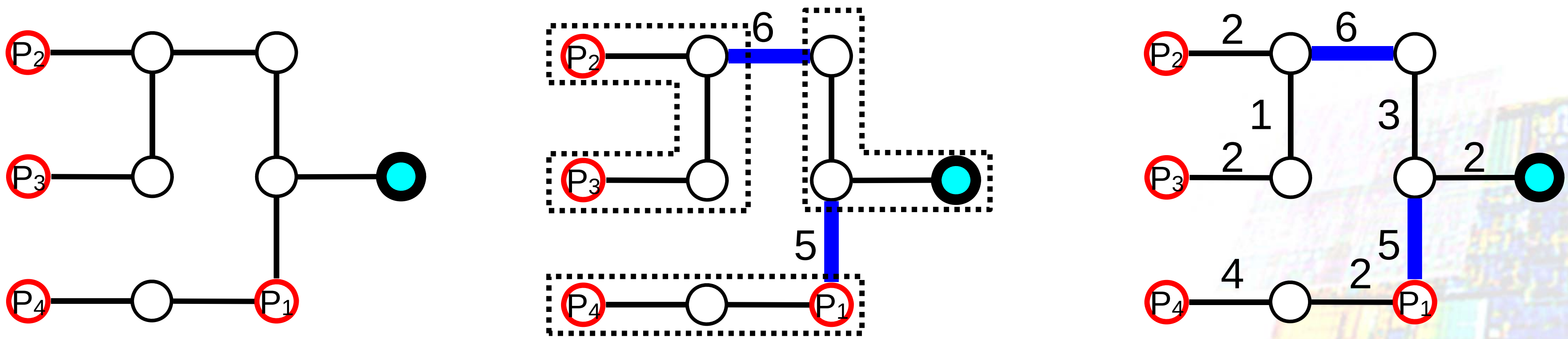
Previous Works

- Antenna avoidance layer assignment [1][2]
  - Step 1: determine separators' locations
  - Step 2: assign each separator to a higher layer
  - Step 3: assign the wire segments of each sub-net to the layers lower than the surrounding separators.
- The potential limitation of [1][2]
  - Because the congestion information is not considered in step 1 and step 2, a bad solution may be found in step 3.



[1] T.-H. Lee and T.-C. Wang, "Simultaneous antenna avoidance and via optimization in layer assignment of multi-layer global routing," ICCAD'10

[2] *D. Wu, J. Hu, and R. Mahapatra,"Antenna avoidance in layer assignment,"IEEE Trans. Comput.-Aided Design Integr. Circuits Syst.*

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  - Antenna-avoidance single-net layer assignment (NALAR)
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Overview of NALAR

- NALAR can determine the separator locations and assign wire segments to the corresponding layers in a single step.

- If a net has at least an antenna-safe assignment solution, NALAR can identify the minimum-cost antenna-safe solution for the net.

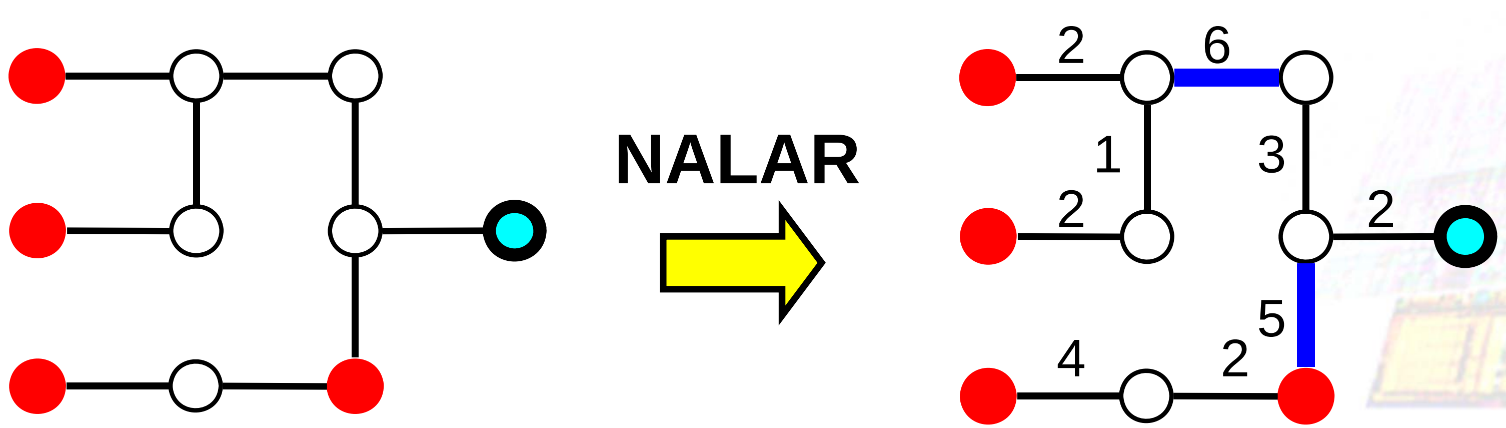
- The objective cost function of NALAR is listed as follows,

$$\mathrm{cost}(t_{i,z}) = \boxed{sepCost \times \mathrm{numSP}(t_{i,z})} + \boxed{viaCost \times \mathrm{numVia}(t_{i,z})} + \boxed{\sum_{e \in t_{i,z}} \mathrm{congCost}(e)}$$

[3] Wen-Hao Liu and Yih-Lang Li, "Negotiation-Based Layer Assignment for Via Count and Via Overflow Minimization,"

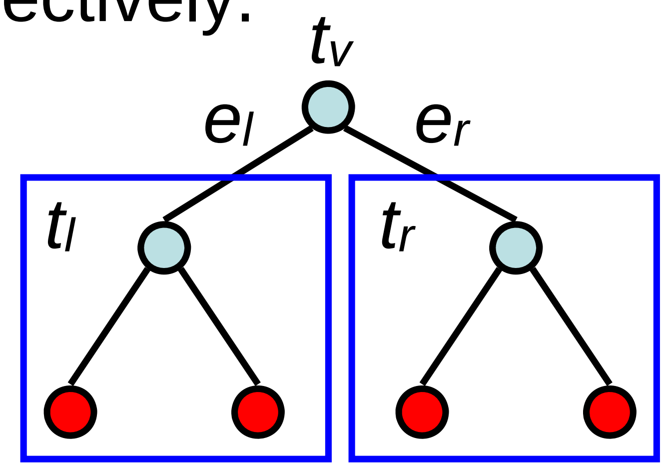
Overview of NALAR

- Bottom-up phase :
  - Enumerate antenna-safe layer assignment solutions and then prune the inferior solutions.
  - Until reaching the root, the minimum-cost antenna-safe solution for entire net can be extracted from the enumerated solution set.
- Top-down phase :
  - Each net edge is assigned to the corresponding layers according to the minimum-cost solution.



Enumerating Layer Assignment Solutions

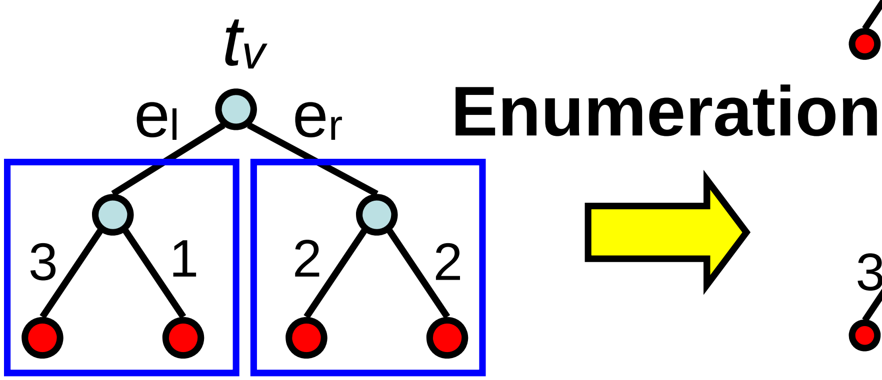
- Let t_l and t_r represent the sub-trees of t_v; e_l and e_r represent the edges connecting the root of t_v to the roots of t_l and t_r, respectively.

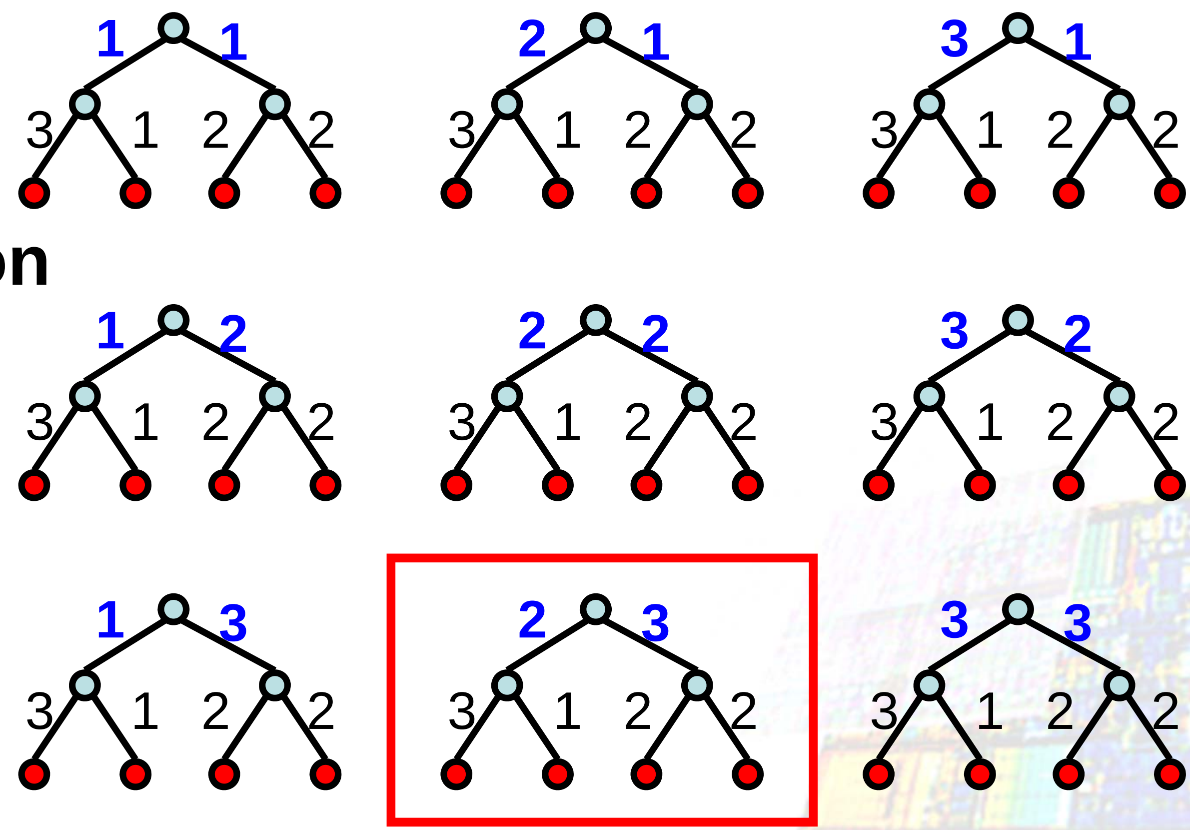


- The set of layer assignment solutions of t_v can be built by enumerating all combinations of the solutions of t_l and t_r with the different layer assignments and the different separator assignments of e_l and e_r.

Enumerating Layer Assignment Solutions

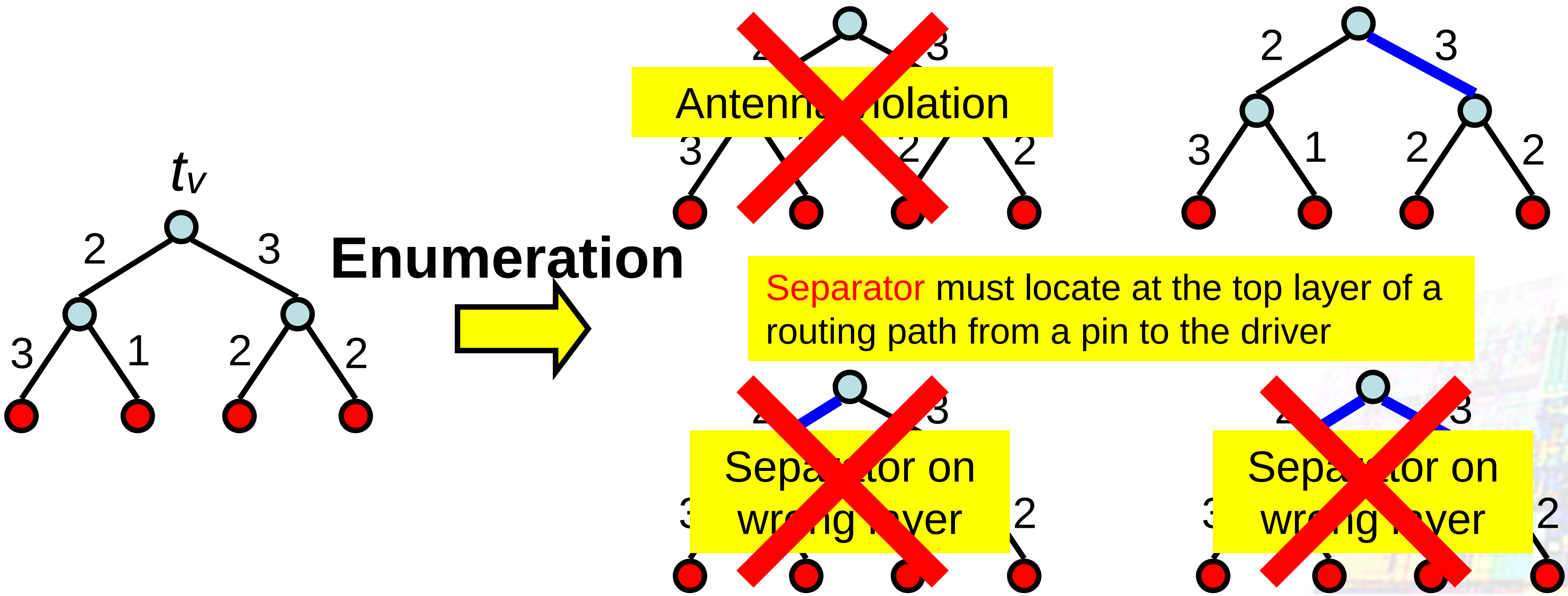
- A solution of t_l and a solution of t_r have been obtained.
- The solutions of t_v can be obtained by composing the solutions of t_l and t_r with the different layer assignments of e_l and e_r.





Enumerating Layer Assignment Solutions

- Each layer assignment solution can derive four solutions with the different separator assignments of e_l and e_r.
- Prune the solutions with the antenna violation and the separators on the wrong layers.



Pruning Inferior Solutions

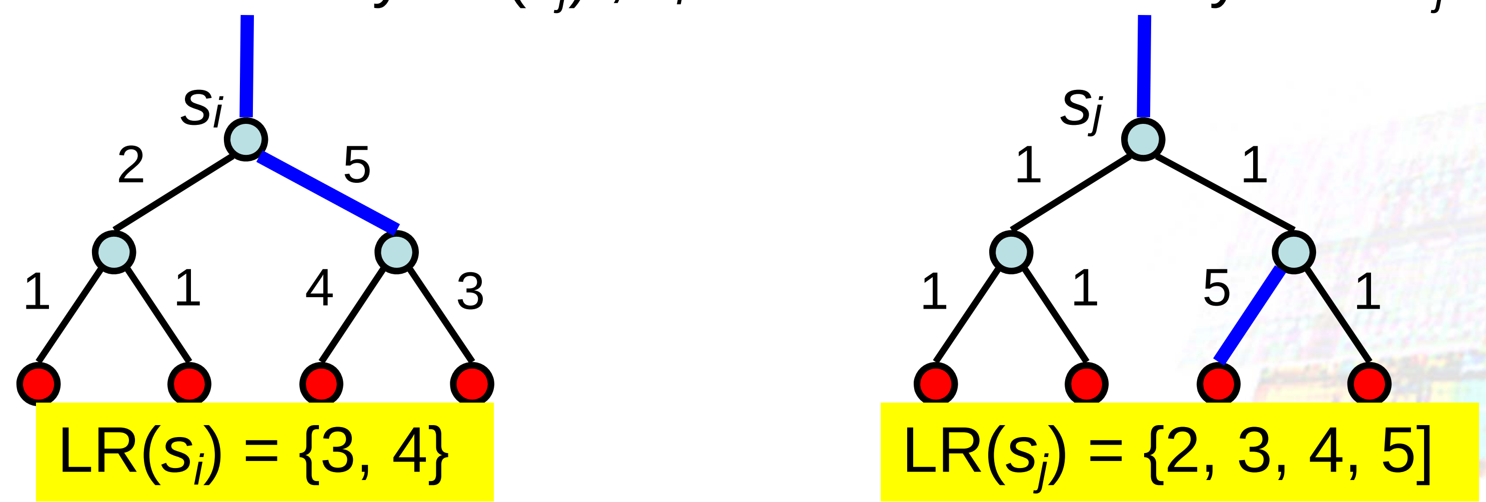
- To limit the size of the solution set in an acceptable range, we discard the *inferior solutions* from the solution set.
- Let s_i and s_j represent the layer assignment solutions of t_v. If the following conditions hold, s_i is regarded as an *inferior solution*.
  - The antenna ratio of s_i is larger than that of s_j.
  - The cost of s_i is larger than that of s_j.
  - The flexibility of s_i is worse than that of s_j.

$$\text{antenna ratio} = \frac{\text{total exposed antenna area}}{\text{the oxide area per gate}}$$

$$\text{cost}(t_{i,z}) = sepCost \times \text{numSP}(t_{i,z}) + viaCost \times \text{numVia}(t_{i,z}) + \sum_{e \in t_{i,z}} \text{congCost}(e)$$

Pruning Inferior Solutions

- Due to the definition of separators, the layers which separators can be legally assigned are restricted.
  - Separator must be located at the top layer of a routing path from a pin to the driver
- Assuming e_v is a separator connecting to the root of t_v, and LR(s_i) represents a set of layers that e_v can be legally assigned as s_i is the layer assignment solution of t_v.
- If LR(s_i) is covered by LR(s_j) , s_i has lower flexibility than s_j.



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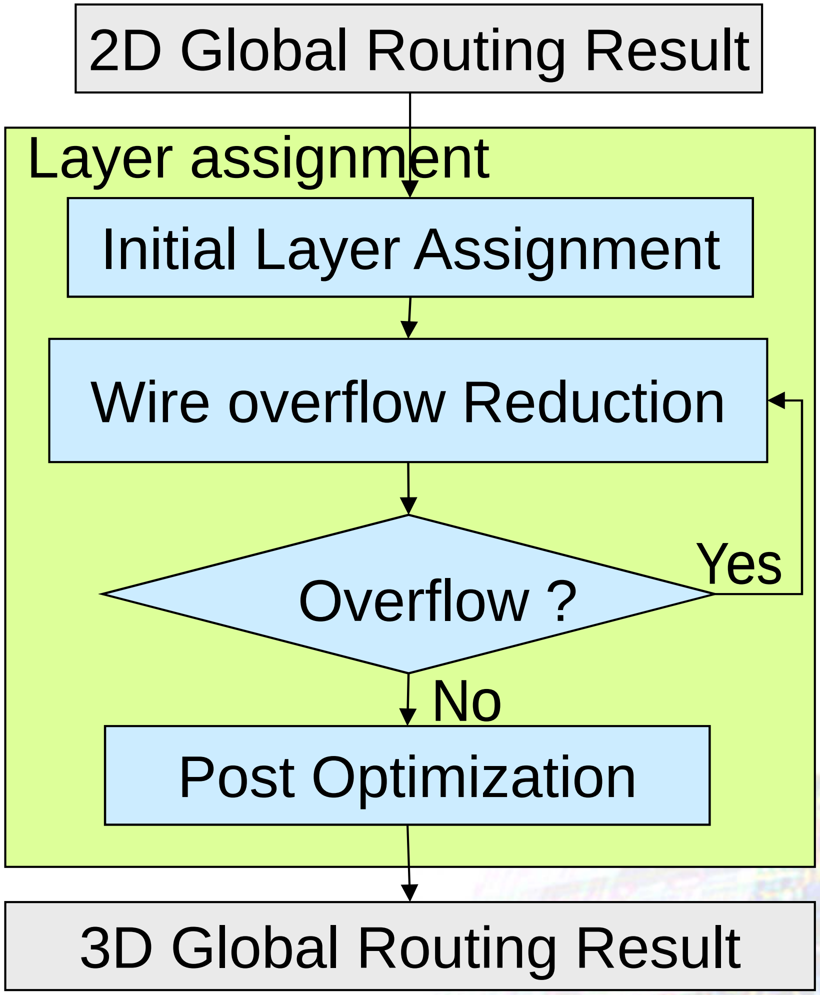
Design Flow of This work

- In this flow, NALAR and NANA are adopted to assign each net.
- NALAR is presented in this work, it can identify the minimum-cost antenna-safe solution, but may identify no solution when no antenna-safe solution exist.
- NANA is presented in [3], it can identify the minimum-cost solution for a net but does not consider the antenna rule.



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Experimental Environment

- The proposed algorithms were implemented in C/C++ language.
- Machine: Intel Xeon 2.4 GHz CPU and 48GB RAM
- ISPD'07 and ISPD'08 global routing benchmarks are used.
- To fairly compare this work with previous layer assignment works, each algorithm reads the same 2D global routing results of NTHU-Route 2.0 [9].

[9] Y.-J. Chang, Y.-T. Lee, and T.-C. Wang, "NTHU-Route 2.0: a fast and stable global router," in *Proc. Int. Conf. Comput.-Aided Des., pages 338-343, 2008*

Comparison between This Work and Existing Works

Benchmark	COLA			NVM			LAVA			This work		
	#vn	vias (10^5)	cpu* (min)	#vn	vias (10^5)	cpu (min)	#vn	vias (10^5)	cpu* (min)	#vn	vias (10^5)	cpu (min)
adaptec1	911	17.69	0.46	709	16.69	0.80	602	17.51	0.73	4	16.72	14.82
adaptec2	879	19.30	0.43	712	18.31	0.70	568	19.07	0.64	0	18.33	12.86
adaptec3	2959	34.91	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5	33.00	60.03
adaptec4	2009	32.15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4	30.90	41.11
adaptec5	4166	52.40	1.65	3744	49.30	2.28	2465	51.9	2.09	0	49.43	53.53
newblue1	328	22.22	0.38	460	21.42	0.58	273	24.95	0.53	6	21.43	4.93
newblue2	681	29.46	0.66	534	28.14	0.94	444	29.15	0.86	1	28.18	11.79
newblue3	466	30.23	0.99	429	29.00	1.58	251	29.42	1.44	1	29.08	29.48
newblue4	874	47.05	1.33	849	44.73	1.68	617	46.59	1.54	0	44.77	20.23
newblue5	3009	84.51	2.25	2766	80.16	3.52	2137	301.91	3.23	0	80.30	77.93
newblue6	3453	74.66	1.76	3280	71.01	2.39	2736	73.83	2.19	0	71.12	33.27
newblue7	10286	166.01	5.10	8628	157.21	6.47	5844	1	5.93	0	157.50	354.41
bigblue1	1841	18.73	0.64	1459	17.60	0.93	1423	18.57	0.85	0	17.65	19.71
bigblue2	392	42.11	0.87	389	40.32	1.24	264	41.72	1.13	0	40.34	16.25
bigblue3	3576	52.43	1.51	3631	50.55	2.49	2692	51.99	2.28	0	50.66	233.01
bigblue4	7676	109.14	2.78	8627	104.69	4.32	5230	108.28	3.96	0	104.93	301.91
sum	**43506**			**41261**			**29671**			**21**		
ratio		**1.049**	**0.036**		**0.998**	**0.053**		**1.046**	**0.123**		**1**	**1**

the number of nets with antenna violations

Reducing the Number of Separators

Benchmark	This work (*sepCost*=0)				This work (*sepCost*=100)				This work (*sepCost*=500)			
	#vn	#sep (10^5)	vias (10^5)	cpu (min)	#vn	#sep (10^5)	vias (10^5)	cpu (min)	#vn	#sep (10^5)	vias (10^5)	cpu (min)
adaptec1	4	9.52	16.72	7.12	2	1.51	17.90	11.20	2	0.94	18.99	13.39
adaptec2	0	6.18	18.33	4.25	0	0.27	18.90	6.35	1	0.17	19.07	6.95
adaptec3	5	33.95	32.97	18.81	6	4.99	35.71	33.23	8	3.72	38.31	38.83
adaptec4	4	26.91	30.88	13.58	4	1.49	32.87	25.19	5	1.09	33.61	28.57
adaptec5	0	32.40	49.41	20.81	0	4.45	52.75	30.87	0	2.89	55.96	34.82
newblue1	6	2.68	21.43	2.28	6	0.21	21.82	3.44	5	0.07	22.03	3.67
newblue2	1	9.58	28.18	5.35	0	0.68	29.59	8.01	0	0.27	30.32	8.76
newblue3	0	18.63	29.06	10.59	0	2.02	31.27	17.11	0	1.28	32.78	18.24
newblue4	0	15.85	44.76	9.27	0	0.95	46.84	14.35	0	0.53	47.59	15.72
newblue5	0	36.79	80.28	32.95	0	2.92	84.32	47.00	0	1.34	87.27	54.80
newblue6	0	23.85	71.11	15.76	0	2.84	74.68	22.47	0	1.08	77.89	24.05
newblue7	0	47.17	157.47	107.31	0	2.86	162.83	148.52	0	1.85	164.59	162.87
bigblue1	0	12.07	17.65	9.77	0	2.87	19.20	12.74	0	1.54	22.26	14.27
bigblue2	0	7.78	40.33	8.49	0	1.28	41.73	12.66	0	0.62	42.94	14.97
bigblue3	0	24.87	50.65	34.27	0	0.73	52.40	53.79	0	0.50	52.81	59.52
bigblue4	0	37.69	104.91	72.65	0	2.05	108.88	105.13	0	1.28	110.26	116.18
sum	**20**				**18**				**21**			
ratio		**1**	**1**	**1**		**0.1**	**1.052**	**1.524**		**0.057**	**1.094**	**1.705**

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Conclusions

- This work presents an antenna-avoidance single-net layer assignment (NALAR) which can identify the minimum-cost antenna-safe layer assignment solution for a net.
- An antenna avoidance layer assignment algorithm adopting NALAR is presented in this work to simultaneously optimize the via count and separators.
- As compared to other works, this work can significantly reduce the number of nets with antenna violations.