Congestion Prediction in Early Stages

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Overview

- Introduction
- Congestion Estimation
  - Preliminary Estimation
  - Detailed Estimation
  - Congestion Redistribution
- Experimental Results

Motivations

- Extremely high design densities result in a major escalation in routing demand
- Over-congestion will lead to an un-routable solution
- Minimizing wirelength does not have significant impact on routability
- Congestion prediction is needed for interconnect analysis in early stages

Motivations

- Real routing
  - The nets would rather pass through the less congested regions to prevent overflow
  - The router may perform rip-up and re-route
- Previous congestion models
  - Over-estimate the congestion at the congested regions
  - Under-estimate the congestion in the surroundings of the congested regions

Contributions

- Improving the accuracy of the predictions
  - Find the regions that are likely to be over-congested first before detailed estimation
  - Re-distribute the wiring capacities appropriately from over-congested regions to less-congested regions to simulate the rip-up and re-route operations in real routing
- Shortening the run-time
  - A simple diagonal-based congestion model is used

Our Approaches

- The packing will be divided into a tile structure
- All multi-pin nets are broken down into 2-pin nets by the minimum spanning tree approach
- Estimate the congestion (horizontal/vertical) at each tile
- A 3-step approach is used
  - Preliminary estimation
  - Detailed estimation
  - Congestion Redistribution

Our Approaches

- **Preliminary Estimation** – Estimate the congestion measure at each tile roughly according to the bounding box of each net
- **Detailed Estimation** – According to the results from the preliminary estimation step, estimate the congestion measure at each tile exactly by using a diagonal-based congestion model
- **Congestion Redistribution** – Move the wires appropriately from over-congested tiles to less congested tiles

Preliminary Estimation

- Assume that all the tiles inside the bounding box, T_k, of a net k have the same probability, $P_k(x, y)$, of being passed through by net k
- Find the area, A_k, of the bounding box of net k
- Find the shortest Manhattan distance, L_k, of net k
- $P_k(x, y) = L_k/A_k$

Preliminary Estimation

0.0	0.5	1.0	1.0	[illegible]	[illegible]
0.5	0.5	3.0	2.0	[illegible]	[illegible]
2.0	3.0	5.0	4.0	4.0	1.0
1.5	3.5	4.0	4.0	4.0	2.0
1.0	2.0	3.0	3.0	3.0	1.0
0.0	1.0	1.0	1.5	1.5	0.5

Area is 12
Shortest Manhattan distance is 6
$P_k(x,y)$ is 0.5

Preliminary Estimation

- Obtain the weight of each tile
  - The weight of each tile, $W(x, y)$, indicates the congestion information of that tile
  - A tile has a smaller weight when it is more likely to be over-congested
  - The weight of each tile is calculated by this equation:

$$W(x,y) = \begin{cases} 1 & : P(x,y) < (c^h_{\max} + c^v_{\max}) \\ \dfrac{c^h_{\max} + c^h_{\max}}{P(x,y)} & : \text{otherwise} \end{cases}$$

c^h_{max} and c^v_{max} are the maximum horizontal and vertical wiring capacities and $P(x, y)$ is $\sum_{\text{all net } k} P_k(x,y)$

Preliminary Estimation

- Calculating $W(x, y)$ (assuming c^h_{max} and c^v_{max} are 2):

Given all $P(x,y)$

0.0	0.5	1.0	1.0	2.0	1.0
0.5	0.5	3.0	2.0	5.0	2.0
2.0	3.0	5.0	4.0	4.0	1.0
1.5	3.5	4.0	4.0	4.0	2.0
1.0	2.0	3.0	[illegible]	[illegible]	[illegible]
0.0	1.0	1.0	[illegible]	[illegible]	[illegible]

1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	0.8	1.0
1.0	1.0	0.8	1.0	1.0	1.0
1.0	[illegible]	1.0	1.0	1.0	1.0
[illegible]	[illegible]	0	1.0	1.0	1.0
[illegible]	[illegible]	0	1.0	1.0	1.0

$P(x,y) > c^h_{\text{max}} + c^v_{\text{max}}$

Thus,

$W(x,y) = (c^h_{\text{max}} + c^v_{\text{max}}) / P(x,y)$

$= 0.8$

Detailed Estimation

- Diagonal-based model
  - Assume that all the nets are routed in its shortest Manhattan distance
  - Divide the bounding box of net k into divisions diagonally
  - Assume that the net will pass through the tiles in the same division with probabilities weighted according to $W(x, y)$

Detailed Estimation

$$E_k(x, y) = \frac{W(x, y)}{\sum_{(i,j) \in T_k(D)} W(i, j)}$$

$W(x, y)$ obtained in preliminary estimation

Sum of $W(x,y)$ in this division is 2.8
$E_k(x,y) = 0.8/2.8 = 0.28$

1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	0.8	1.0
1.0	1.0	0.8	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0
1.0	1.0	1.0	1.0	1.0	1.0

Calculating $E_k(x, y)$

1.0	[illegible]	0.36	0.28
0.5	0.28	0.36	0.5
0.36	0.36	0.5	1.0

Congestion Redistribution

- Rip-up and re-route will be performed in real routing to prevent over-congestion
- Move the estimated congestion measures from the over-congested tiles to the less congested tiles to achieve the same goal

Congestion Redistribution

After detailed estimation

1.0	1.25	1.50	1.75	1.88	1.50
1.25	1.86	2.46	2.68	3.86	2.88
2.46	**0.28** 2.21	**3.80**	3.26	2.88	2.96
2.21	**2.32**	3.21	2.78	2.64	2.04
1.50	1.68	2.23	2.31	2.05	1.75
1.0	1.50	1.58	1.68	1.70	1.60

Contribute from net *k*

1.0	0.5	0.36	0.28
0.5	**0.28**	0.36	0.5
0.36	0.36	0.5	1.0

Blockages Handling

- Calculate the reduced routing resource due to blockages
- Re-calculate the weight of each tile according to the reduced routing resource

$$W'(x,y) = W(x,y) \times (1 - B(x,y))$$

$B(x, y)$ is the percentage of the reduced routing resource at tile (x, y)

Experimental Results

- Test Cases: ISPD-02 suite circuits
- Placer: Capo (from VLSI CAD Bookshelf)
- Global router: Labyrinth (from VLSI CAD Bookshelf)
- Environment: 750MHz processor with 2Gb memory
- Congestion models: our 3-step approach, Lou's and Westra's Model

Experimental Results – Test cases

Test Cases	No. of Cells	No. of Nets	No. of 2-pin Nets	No. of Tiles
ibm01	12506	14111	36455	57 x 57
ibm02	19342	19584	61615	82 x 82
ibm03	22853	27401	66172	89 x 87
ibm04	27220	31970	73889	85 x 86
ibm05	28146	28446	97862	60 x 60
ibm06	32332	34826	93366	81 x 82
ibm07	45639	48117	127522	97 x 97
ibm08	51023	50513	154377	104 x 103
ibm09	53110	60902	161186	118 x 118
ibm10	68685	75196	222371	194 x 189
ibm11	70152	81454	199332	130 x 129
ibm12	70439	77240	240520	171 x 171
ibm13	83709	99666	257409	141 x 141
ibm14	147088	152772	394044	151 x 151
ibm15	161187	186606	529215	170 x 169
ibm16	182980	190048	588775	204 x 203
ibm17	184752	189581	670455	182 x 182
ibm18	210341	201920	617777	163 x 163

Experimental Results – Estimation Errors (1)

Test Cases	Wiring Capacities	Lou's Model		Westra's Model		Diagonal-based Model		3-step Approach	
		Mean	Sdv.	Mean	Sdv.	Mean	Sdv.	Mean	Sdv.
ibm01	27	17.36	14.87	15.06	13.68	14.32	13.67	12.63	11.30
ibm02	46	16.96	18.10	14.12	17.12	11.63	15.19	10.15	13.16
ibm03	45	32.34	26.30	27.59	25.70	24.29	23.90	20.66	21.88
ibm04	140	4.51	4.90	4.37	6.17	4.12	4.65	4.10	4.62
ibm05	70	27.21	16.56	23.27	15.69	18.28	13.76	14.22	11.82
ibm06	47	23.43	20.16	21.20	20.07	17.61	18.54	14.65	16.29
ibm07	53	13.51	12.91	12.05	12.47	10.44	10.72	9.44	9.40
ibm08	400	2.17	2.83	2.07	4.18	1.86	2.71	1.85	2.64
ibm09	50	15.76	15.61	13.62	15.80	11.43	12.63	10.34	10.78
ibm10	50	18.16	15.56	11.71	14.27	9.13	10.75	8.36	9.12
ibm11	55	14.38	13.31	11.55	12.65	10.28	10.84	9.43	9.24
ibm12	60	20.79	18.98	14.86	21.27	11.42	13.28	10.16	10.84
ibm13	60	14.67	13.08	11.97	12.48	10.21	10.51	9.35	9.14
ibm14	65	13.38	11.49	10.52	10.47	9.88	9.42	9.32	8.18
ibm15	80	17.19	14.50	12.06	13.32	10.33	10.05	9.28	8.34
ibm16	60	19.54	16.01	14.47	15.18	11.58	11.70	10.58	10.29
ibm17	80	18.56	14.48	12.70	11.92	10.57	9.91	9.69	8.61
ibm18	70	17.20	14.36	14.56	13.13	12.76	11.49	11.65	10.23
Average		17.06	14.87	15.06	13.68	14.32	13.67	12.63	11.30
Comparing w/Lou's		***0.00%***	***0.00%***	***-19.34%***	***-3.20%***	***-31.58%***	***-19.05%***	***-39.48%***	***-29.61%***

***More congested situation** (0-5% over-congested tiles during global routing)

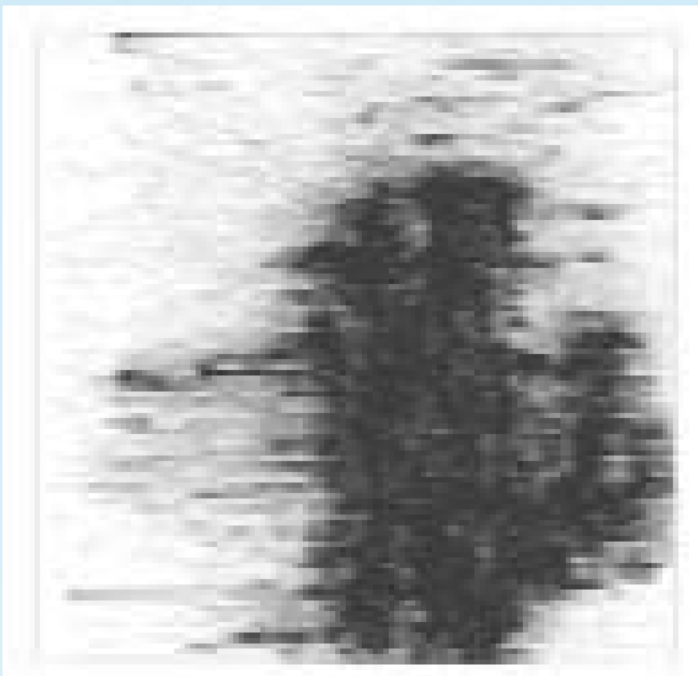
Experimental Results – Estimation Errors (2)

Test Cases	Wiring Capacities	Lou's Model		Westra's Model		Diagonal-based Model		3-step Approach	
		Mean	Sdv.	Mean	Sdv.	Mean	Sdv.	Mean	Sdv.
ibm01	30	12.78	11.08	11.18	10.21	11.73	11.12	10.95	9.92
ibm02	55	9.13	9.78	8.04	9.47	7.14	8.94	6.81	8.29
ibm03	50	13.37	13.35	10.93	13.06	9.18	10.93	8.15	9.13
ibm04	150	3.90	4.08	3.78	4.90	3.54	3.85	3.54	3.83
ibm05	80	12.87	9.06	10.60	8.11	9.62	7.49	9.23	6.96
ibm06	55	10.74	9.97	10.06	9.97	9.57	9.83	8.82	8.69
ibm07	60	9.44	8.82	8.50	8.55	8.07	7.90	7.72	7.35
ibm08	500	1.66	2.07	1.56	2.92	1.42	1.96	1.42	1.95
ibm09	60	10.18	10.25	8.92	10.44	8.30	8.76	7.95	8.09
ibm10	60	12.42	10.78	8.11	9.80	6.51	7.37	6.31	6.92
ibm11	65	10.47	9.68	8.36	8.98	7.75	7.87	7.46	7.28
ibm12	70	14.94	14.13	10.22	15.42	7.72	8.75	7.38	7.68
ibm13	70	10.56	9.54	8.53	8.84	7.74	7.74	7.46	7.26
ibm14	75	10.37	8.91	8.07	8.04	7.80	7.40	7.58	6.80
ibm15	90	12.19	10.66	8.32	9.41	7.70	7.24	7.46	6.71
ibm16	70	13.04	10.73	9.51	10.19	8.07	7.69	7.80	7.21
ibm17	90	12.52	9.74	8.18	7.59	7.38	6.50	7.20	6.12
ibm18	85	8.66	7.06	7.03	6.10	6.97	5.88	6.80	5.60
Average		10.51	9.43	8.33	9.00	7.57	7.62	7.22	6.99
Comparing w/Lou's		***0.00%***	***0.00%***	***-20.78%***	***-4.52%***	***-28.03%***	***-19.13%***	***-31.29%***	***-25.87%***

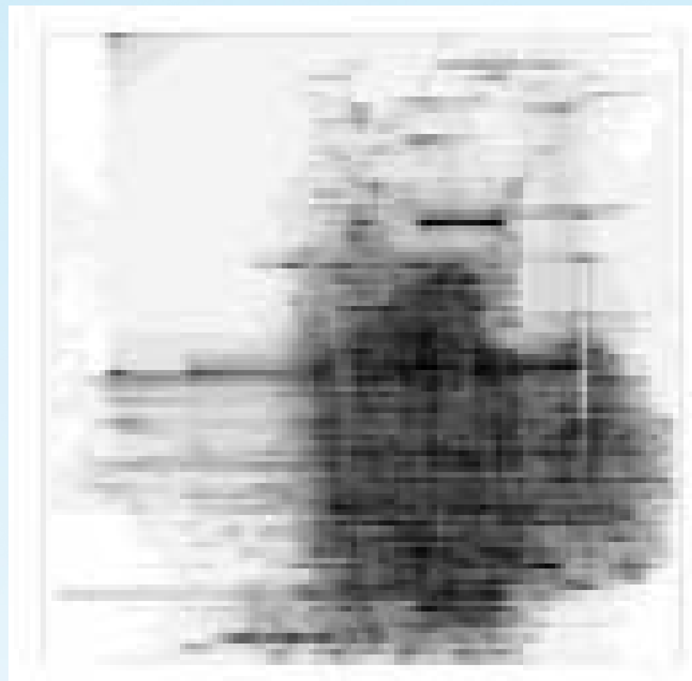
***Less congested situation** (No over-congested tiles during global routing)

Experimental Results

Congestion measures for horizontal net segments



Global routing

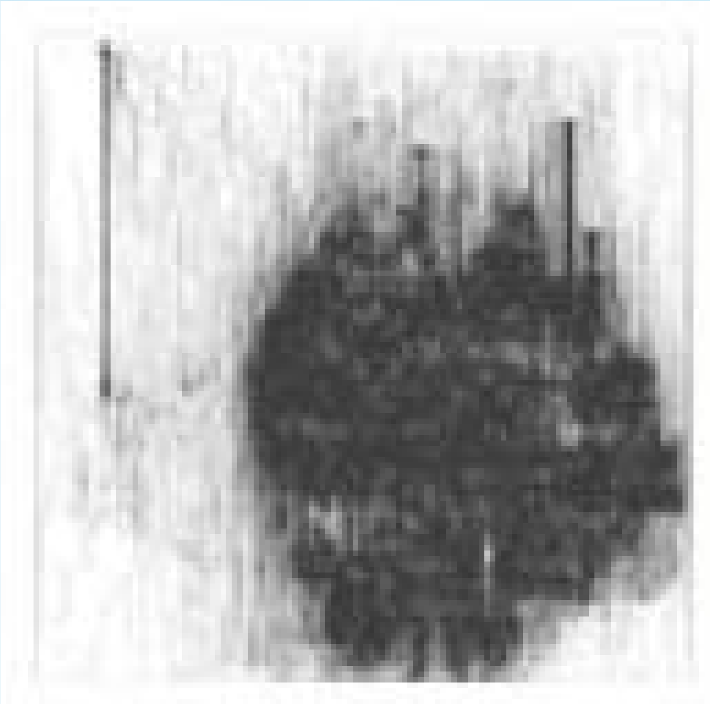


Westra's model

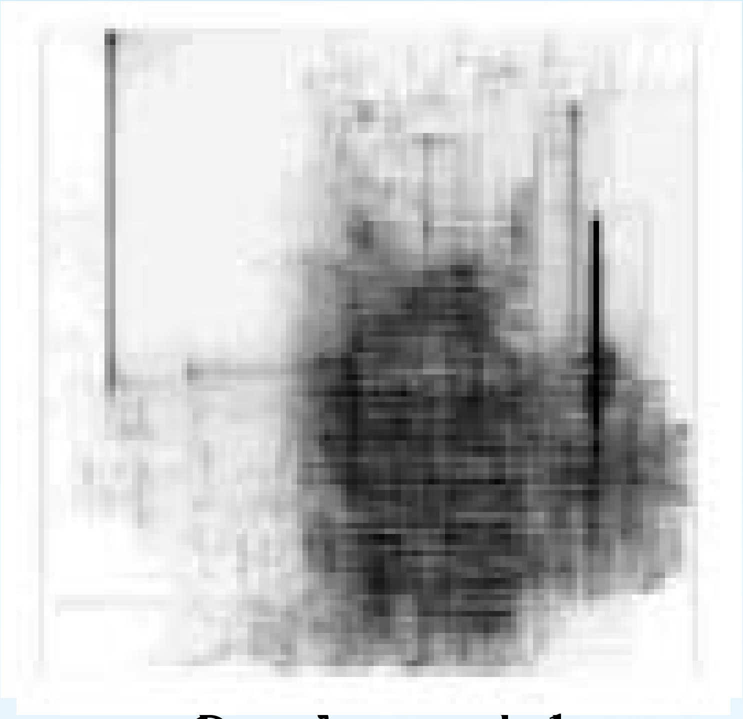
Our approach

Experimental Results

Congestion measures for vertical net segments



Global routing



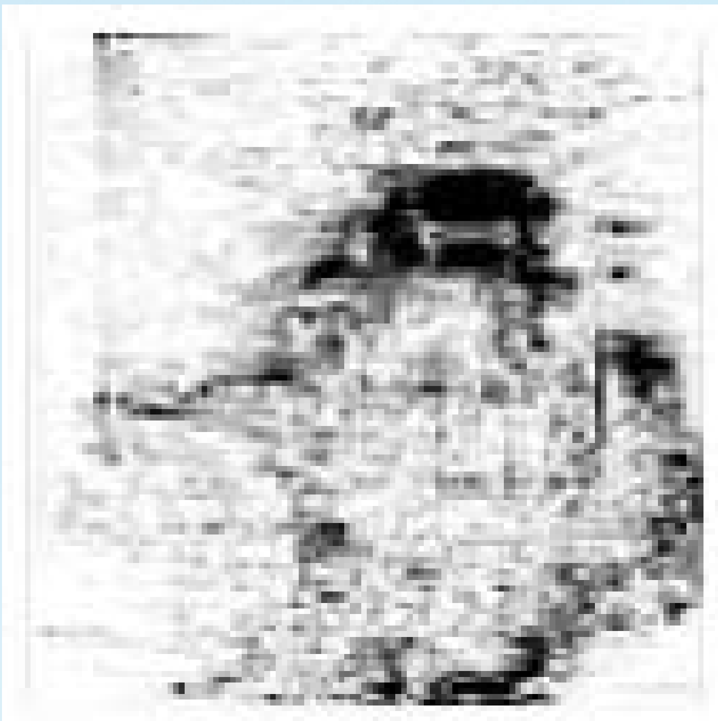
Westra's Model

Ou's model

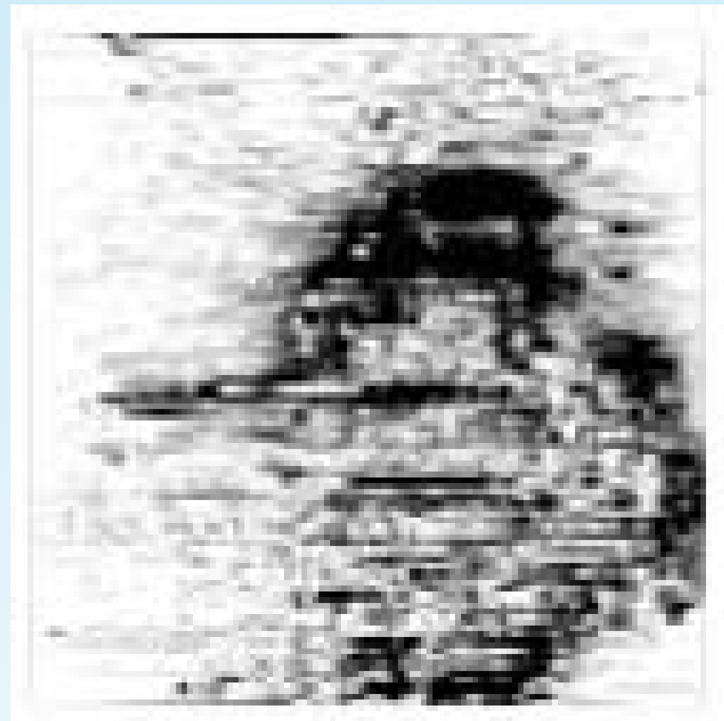
Our approach

Experimental Results

Estimation errors for horizontal net segments



Our approach

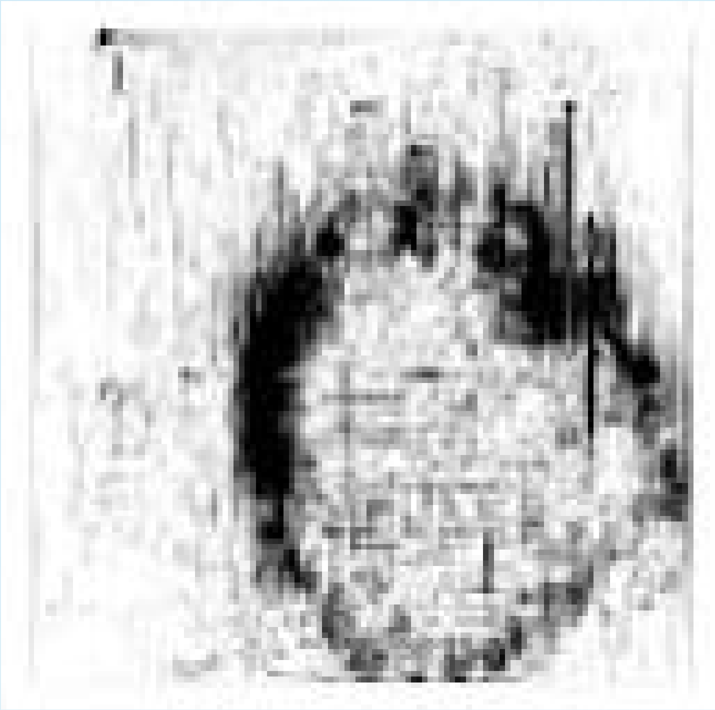


Westra's model

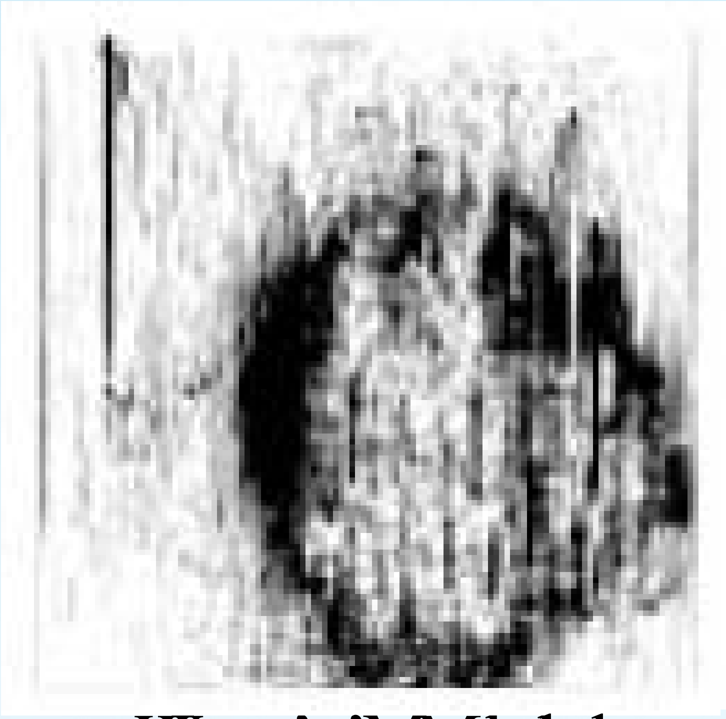
Lou's model

Experimental Results

Estimation errors for vertical net segments



Our approach



West's Model

Laura's Model

Experimental Results – Runtime

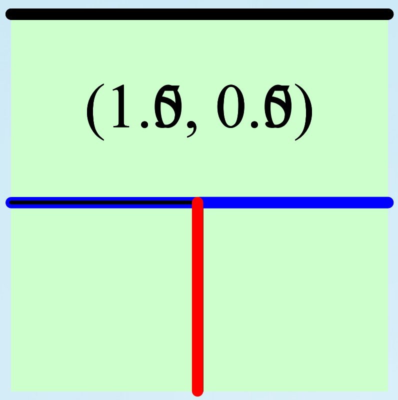
Test Cases	Lou's Model (*s*)	Westra's Model (*s*)	Diagonal-based (*s*)	3-step Approach (*s*)	Global Routing (*s*)
ibm01	0.24	0.14	0.13	0.31	190
ibm02	0.46	0.28	0.27	0.60	454
ibm03	0.92	0.58	0.53	1.10	987
ibm04	0.94	0.54	0.50	1.00	806
ibm05	1.03	0.60	0.55	1.20	1058
ibm06	0.64	0.35	0.34	0.77	642
ibm07	1.16	0.87	0.67	1.44	1206
ibm08	1.46	1.00	0.94	1.96	2021
ibm09	1.50	1.02	0.95	2.02	2217
ibm10	5.09	4.56	4.20	7.93	8820
ibm11	2.25	1.61	1.51	3.07	3021
ibm12	6.00	5.49	5.08	9.60	10543
ibm13	2.93	2.05	1.90	3.91	4680
ibm14	4.45	3.14	2.94	5.93	9480
ibm15	6.99	5.51	5.11	10.21	14220
ibm16	8.01	6.32	5.90	11.68	15684
ibm17	9.77	7.81	7.27	14.24	20547
ibm18	4.84	3.14	2.92	6.43	11235
Average	3.26	2.50	2.32	4.63	5990

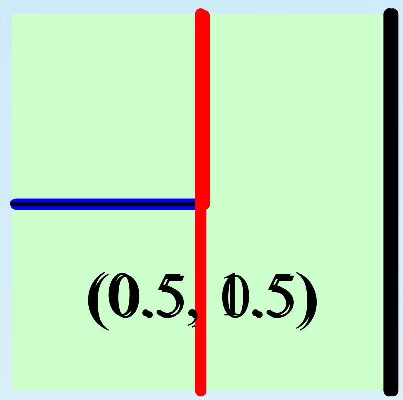
Conclusion

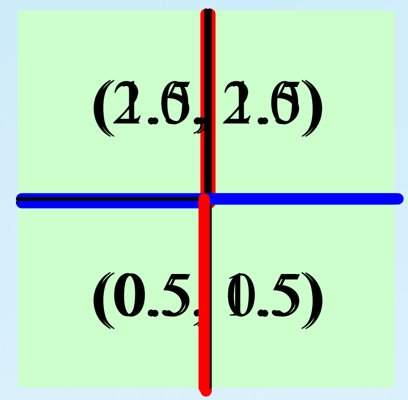
- A 3-step approach of congestion estimation has been proposed
- Results show that it is a more accurate congestion estimation model
  - Does not over-estimate the congestion at the congested regions
  - Does not under-estimate the congestion in the surrounding of the congested regions

Q & A

Detailed Estimation







$$E_k^v(x,y) = \frac{0.5 \times P_k(x,y)}{(1.5+0.5)}$$

$$E_k^h(x,y) = \frac{1.5 \times P_k(x,y)}{(1.5+0.5)}$$

$$E_k^v(x,y) = \frac{1.5 \times P_k(x,y)}{(0.5+1.5)}$$

$$E_k^h(x,y) = \frac{0.5 \times P_k(x,y)}{(0.5+1.5)}$$

$$E_k^v(x,y) = \frac{2.0 \times P_k(x,y)}{(2.0+2.0)}$$

$$E_k^h(x,y) = \frac{2.0 \times P_k(x,y)}{(2.0+2.0)}$$