Non-slicing Floorplanning-based Crosstalk Reduction on Gridless Track Assignment for a Gridless Routing System

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Outline

- Introduction
- Crosstalk-Driven GTA
- Detailed Routing
- Experimental Results
- Conclusion
Interconnection

- Routing – connect all pins of the same net using wires of available layers for all nets
Cell-Based Routing Example
Why Gridless and Crosstalk-Driven Router?

- Crosstalk induced by adjacent wires increases the coupling capacitance and delay of the wires.
- Wide space and fat wire are used for crosstalk and delay optimization.
- Gridless routers are more flexible for variable-rule routing than grid-based routers.
Routing Flow

Global router

Global paths

GTA Preprocess: IRoute Extraction

Initial GTA

Extended O-tree
Floorplan Based Assignment refinement

Sub-panel re-arrangement

Gridless track assignment (GTA)

Crosstalk reduction

Detailed routing

Gridless Detailed routing

Pattern routing

Detailed routing preprocess: Routing tree construction

Track assignment results
Contributions of this work

- This work presents a complete three-stage gridless routing system consisting of:
  - A congestion-driven global router
  - A crosstalk-driven gridless TA (GTA)
  - Enhanced NEMO with fast PMT extraction for detailed router.
Preliminaries – Gridless Basics

Zero-width Model
Implicit connection graph-based router

Nonzero-width Model
Tile-based router
Preliminaries - Implicit Connection Graph-Based Router

- Routing flow
  - Construct a slit and interval tree using the raw wires
  - Construct implicit connection graph using (a) 2-D point array(s) by extending the borders of expanded wires
    - Single routing plane
    - Multiple routing planes with each plane integrating all wires of two adjacent layers
  - Grid maze over the implicit connection graph
Preliminaries - Implicit Connection Graph-Based Router

Fast routing graph construction

• J. Cong et al., “An Implicit connection graph maze Routing Algorithm for ECO routing,” in ISPD99

Efficient query data structure
(Slit tree + Interval Tree)
Preliminaries - Implicit Connection Routing Graph
Preliminaries - Implicit Connection Graph Example
Preliminaries - Implicit Connection
Graph Example – cont.
Preliminaries - Implicit Connection Graph Example – cont.
Preliminaries - Tile-Based Router

Maximum horizontal strip  Maximum vertical strip
Preliminaries - Tile-Based Router

- Routing flow
  - Add contours to existing wires
  - Construct corner-stitching tile plane by extending the borders of the expanded wires
  - Extract starting segments
  - Propagate routing paths over the tile plane
  - Construct final path from a series of connected tiles (abut or overlap with neighboring tiles)
Preliminaries - Tile Propagation – cont.

- Edge propagation example

Source: Jeremy Dion in WRL research report 95
Preliminaries - Path Construction

- Path Construction
  - Edge list is converted into tile list
  - Minimize corner or any constraint cost
  - Ideal via position is very important for an optimum path
Preliminaries - Tile-Based Router Example

- Contour Insertion
Preliminaries - Tile-Based Router Example

- Corner Stitching Tile Plane Creation
Preliminaries - Tile-Based Router Example

- Tile Propagation
Preliminaries - Tile-Based Router Example

- Path construction
Preliminaries - Features of NEMO

- Multi-Plane Routing Graph
- Tile plane but not grid plane
- Non-zero width wire model
- Pseudo Maximum (horizontally or vertically) Stripped Tile (PMT) Extraction and Propagation
- Pseudo Blockage Insertion & Gridline Reduction

Preliminaries - Multi-Plane Routing Graph

An 3-layer routing example
Preliminaries - Why Tile, Not Grid

Grids on adjacent Layers don’t align
Preliminaries - Non-Zero Width Wire Model

Half width separation

rule rule

$W_s$ $W_s$
Preliminaries - Multi-Layer Routing

Layer 1

Layer 2: T(1,1), T(2,1), T(3,1)
T(1,2), T(2,2), T(3,2)
Preliminaries - Path Search by PMT

Maximum horizontally stripped

Diagram showing a path search from point A to point B.
Preliminaries - PMT Extraction – Tile Query

- Point query
- Three Cut lines
- three internal nodes
Preliminaries - PMT Extraction – Merging
Preliminaries - IRoutes

- IRoute 1
- IRoute 2
- IRoute 3
- Pin
- Pseudo pin
Preliminaries – GTA Problem

Cut line

Horizontal panel

sub-panel

Vertical panel

i1 i2 i3

i4

i5

i6

i7
Preliminaries – Crosstalk Model

- Crosstalk Model
- $f$ is switching factor
- $l$ is coupling length
- $d$ is distance

$$C_c(i, j) = \alpha \cdot f_{i,j} \cdot \frac{l_{i,j}}{d_{i,j}^\beta}$$
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Crosstalk-Driven GTA

GTA Preprocess: IRoute Extraction

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Sub-panel re-arrangement

Gridless track assignment

Crosstalk reduction
Initial GTA
Extended O-Tree Based Assignment Refinement (EOBAR)

(a) Overlap graph

(b) O-tree

(c) Extended O-tree

external insertion location

internal insertion location
Extended O-Tree Based Assignment Refinement
Extended O-Tree Based Assignment Refinement

(a) 

(b) 

(c) 

(d) 

Infeasible
Extended O-Tree Based Assignment Refinement

- Insertion is realized by tentative plow
  - IRT: IRoute under test
  - IL: Insertion Location
  - Plowing direction:

Type I: plow IRT path

Type II: plow IRoute overlap to IRT

Type III: plow effect propagation to neighboring path
Sub-panel Rearrangement

1. Sub-panel Rearrangement Diagram

2. Diagram showing the rearrangement of panels labeled HIR1 to HIR4.
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- Experimental Results
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Detailed routing

- Track assignment results
- Detailed routing preprocess: Routing tree construction
- Pattern routing
- Gridless Detailed routing
Routing Tree Construction
Routing Tree Construction
Gridless Detailed Routing
Bin-Based Data Structure and Fast PMT Extraction

Bin-based data structure
Experimental Results

- All routing cases were conducted on a 1.2GHz Sun Blade-2000 workstation with 2GB RAM
- Six MCNC benchmark circuits using three routing layers
### Experimental Results

**Table 1. Comparison of routing performance between NEMO and this work.**

<table>
<thead>
<tr>
<th></th>
<th>NEMO</th>
<th></th>
<th>This work</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time (Tn:sec)</td>
<td>Mem (MB)</td>
<td>Time (Tt:sec)</td>
<td>Mem (MB)</td>
</tr>
<tr>
<td>s5378</td>
<td>2.4</td>
<td>10</td>
<td>2.10</td>
<td>22</td>
</tr>
<tr>
<td>s9234</td>
<td>1.7</td>
<td>9</td>
<td>1.45</td>
<td>21</td>
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<td>15</td>
<td>4.43</td>
<td>25</td>
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<tr>
<td>s15850</td>
<td>8.8</td>
<td>18</td>
<td>6.51</td>
<td>27</td>
</tr>
<tr>
<td>s38417</td>
<td>37.2</td>
<td>48</td>
<td>13.46</td>
<td>37</td>
</tr>
<tr>
<td>s38584</td>
<td>73.7</td>
<td>66</td>
<td>30.52</td>
<td>45</td>
</tr>
<tr>
<td>Tn/Tt</td>
<td>1.72</td>
<td></td>
<td>1</td>
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</tbody>
</table>
## Experimental Results

Table 2. Statistics of crosstalk reduction for fixed- and variable-rule routings.

<table>
<thead>
<tr>
<th>Circuit</th>
<th>Initial assignment</th>
<th>O-tree based refinement + HIR re-arrangement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Coupling cap. x 10³ (C1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Coupling cap. x 10³ (C2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RR (%)</td>
</tr>
<tr>
<td></td>
<td>FR</td>
<td>VR</td>
</tr>
<tr>
<td>S5378</td>
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<td>.123</td>
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<td>.086</td>
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<tr>
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<td>.294</td>
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<tr>
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<tr>
<td>S38417</td>
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<td>.794</td>
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<td>1.402</td>
<td>1.026</td>
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<tr>
<td>Ave.</td>
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</table>
Experimental Results

• Table 3. Comparison of routing results between this work and NEMO.

<table>
<thead>
<tr>
<th></th>
<th>Global Routing + NEMO</th>
<th>Global Routeing + crosstalk driven GTA + fast PMT extraction NEMO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Run time (sec)</td>
<td>W.L. ($\times 10^4 \mu m$)</td>
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<tr>
<td></td>
<td>FR VR</td>
<td>FR VR</td>
</tr>
<tr>
<td>s5378</td>
<td>2.4 3.74</td>
<td>7.4 7.6</td>
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<td>1.7 2.69</td>
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<td>s38584</td>
<td>73.7 143.39</td>
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<tr>
<td>Comp.</td>
<td>2.66 4.17</td>
<td>0.93 0.94</td>
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</table>
Experimental Results

Table 4. Comparison of fixed-rule routing results of a commercial routing tool and this work.

<table>
<thead>
<tr>
<th>circuit</th>
<th>Run time (sec)</th>
<th>Wire length ($\times 10^4 \mu$m)</th>
<th>Coupling capacitance (pf)</th>
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</thead>
<tbody>
<tr>
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<td>CR wt SI</td>
<td>This work</td>
</tr>
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<tr>
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<td>4.13</td>
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<tr>
<td>s15850</td>
<td>5.34</td>
<td>49</td>
<td>23</td>
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<tr>
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<td>14.04</td>
<td>110</td>
<td>52</td>
</tr>
<tr>
<td>s38584</td>
<td>22.65</td>
<td>157</td>
<td>72</td>
</tr>
<tr>
<td>Comp.</td>
<td>1</td>
<td>7.92</td>
<td>1</td>
</tr>
</tbody>
</table>
Conclusion

- This work presents a complete three-stage gridless routing system.
- Experimental results reveal that the proposed gridless routing system can perform over 2.66 times faster than NEMO.
- As compared with a commercial routing tool, this work yields an average runtime speedup of 7.92 times and an average 15% reduction rate in coupling capacitance.
Acknowledgements

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  - 博班: 林彥宏、林志達
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