Octilinear Redistributive Routing in Bump Arrays

Renshen Wang
Chung-Kuan Cheng

Department of Computer Science & Engineering
University of California, San Diego
Outline of Today’s Talk

- Introduction & Background
- Redistribution Layer (RDL) Routing Problem Formulation
- Previous Approaches
  - Grid Network Approach
    - Min-cost max-flow and RDL routing solution
    - Grid network construction
- Experimental Results
- Conclusions and Future Works
Background

- Chip to package connections
  - Wire bonding → Ball grid array
- On-chip I/O patterns & Array patterns
  - Possible mismatch
Redistribution Layer

- A “re-distribution layer” (RDL) is used to connect I/O pads to solder bumps

- RDL routing
Redistribution Layer (RDL) Routing Problem Formulation

- Connect I/O pads to bumps

![Diagram of bump, wire, and pad]

- Given wire width
- Minimum wire spacing

- Characteristics
  - Interchangeability (no crossings)
  - 8-geometry wires are usually used ("− | ×") to reduce wire length and routing congestion
Previous Approaches

- Manual design
- Routing on graph models
  - Effective for Manhattan routing, but not for handling 45° wires
- Design for special patterns
Grid Network Approach

- Manhattan routing using a grid network
  - Construct a grid in the bump array
  - Routing solution $\leftrightarrow$ network flow solution

Unit size = wire width + spacing
Edge capacity = 1
Vertex capacity = 1
Grid Network Approach

- Octilinear routing
  - Octilinear grid?

Not enough spacing between 45° tracks
Excessive crossing points
Octilinear Grid for RDL Routing

- Line shifting
  - Topologically shift the 45° tracks on to Manhattan grid
  - Preserve the actual positions of 45° tracks
Octilinear Grid for RDL Routing

- Spacing violations avoided by min-cost max-flow on the grid
  - Between a grid node and a 45° track
  - Not a violation between an off-grid node and an H/V track
Octilinear Grid for RDL Routing

- Octilinear routing on the grid network
  - Construct a Manhattan grid in the bump array
  - Add “topologically shifted” 45° tracks by area

- Routing solution ↔ network flow solution
Detailed Grid Construction

- Crossing area of H/V channels

\[ C_{cross} = \left[ \left( \frac{W_H + W_V}{\sqrt{2} - s} \right) / (w + s) \right] \]

- \((C_{cross} - 2) 45^\circ\) tracks distributed at center

- Actual diagonal capacity = 4
Detailed Grid Construction

- Channel segment area

\[ C_{\text{seg}} = \left\lfloor \left( \frac{L_{\text{seg}} + W_{\text{seg}}}{\sqrt{2} - s} \right) / (w + s) \right\rfloor \]

- \((C_{\text{seg}} - 1)\) 45° tracks distributed at center

- \(C_{\text{seg}} = 4\)
Detailed Grid Construction

- On the boundary of 2 adjacent areas

If there is a spacing violation, shift the 45° tracks onto the same grid node.
Detailed Grid Construction

- Missing bump area
  - Extend the tracks in the channel segments
  - Add two diagonal tracks
  - $(C_{\text{seg}} - 1)$ tracks in each channel segment

- Min-cost max-flow $\rightarrow$ RDL routing solution
Wire Smoothing

- Min-cost max-flow gives shortest paths
  - With possible zigzag shapes
- Iterative post processing

Repeat {
  For each unit of flow:
    1) Delete the flow unit from source to sink;
    2) Find a shortest path with min #turnings;
    3) Resume the flow unit by the new path;
} Until no path is changed in the iteration
Shortest Path with Minimal Number of Turnings

- Dynamic programming on Shortest path algorithm
  - "α - β routing", [Hu1985]
  - 1 node → 8 states
  - distance → (distance, #turnings)

- $O(n \log n)$ time
Experimental Results

- Two different pad distributions in the same bump array
Experimental Results

- More test cases (running time counted in seconds)
Conclusions and Future Works

- First octilinear RDL router
  - Automatic and optimal RDL routing is possible
- Topological “line shift” for octilinear grid

- Limited for single layer cases
  - System complexity $\uparrow$ & I/O connections $\uparrow$
  - Multiple redistribution layer
Q & A

- Thank you for your attention

This work is done in Mentor Graphics Corporation during an internship