Octilinear Redistributive Routing in Bump Arrays

Renshen Wang
Chung-Kuan Cheng

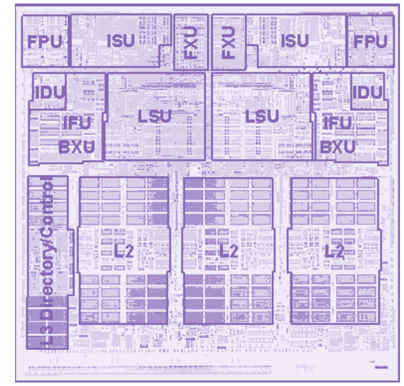
Department of Computer Science & Engineering
University of California, San Diego

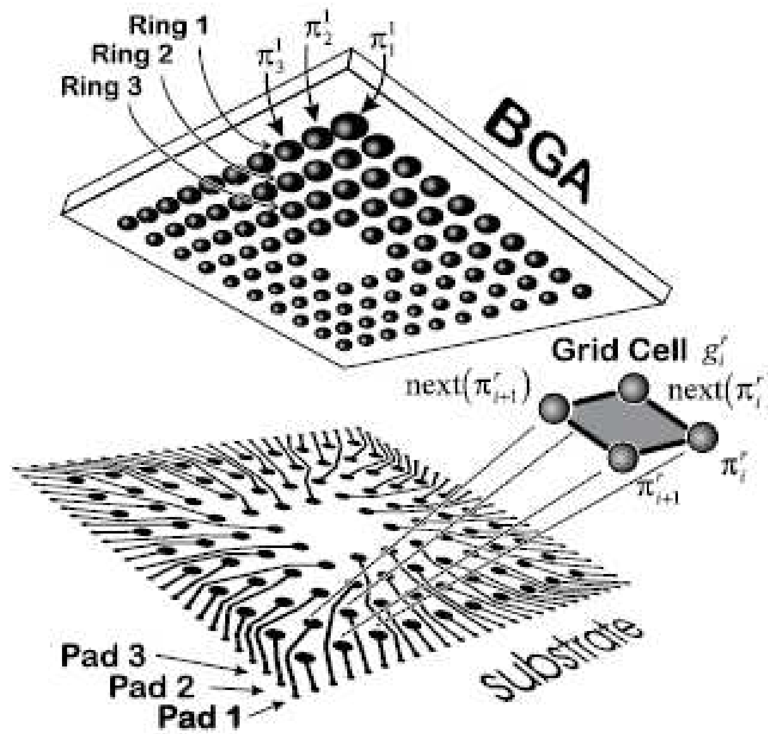
Outline of Today's Talk

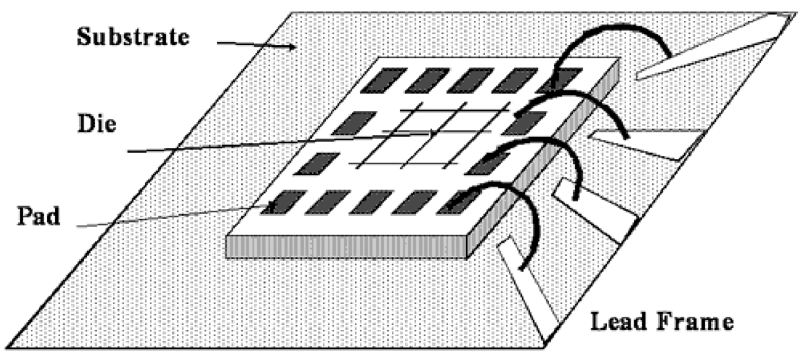
- Introduction & Background
- Redistribution Layer (RDL) Routing Problem Formulation
- Previous Approaches
- Grid Network Approach
  - Min-cost max-flow and RDL routing solution
  - Grid network construction
- Experimental Results
- Conclusions and Future Works

Background

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

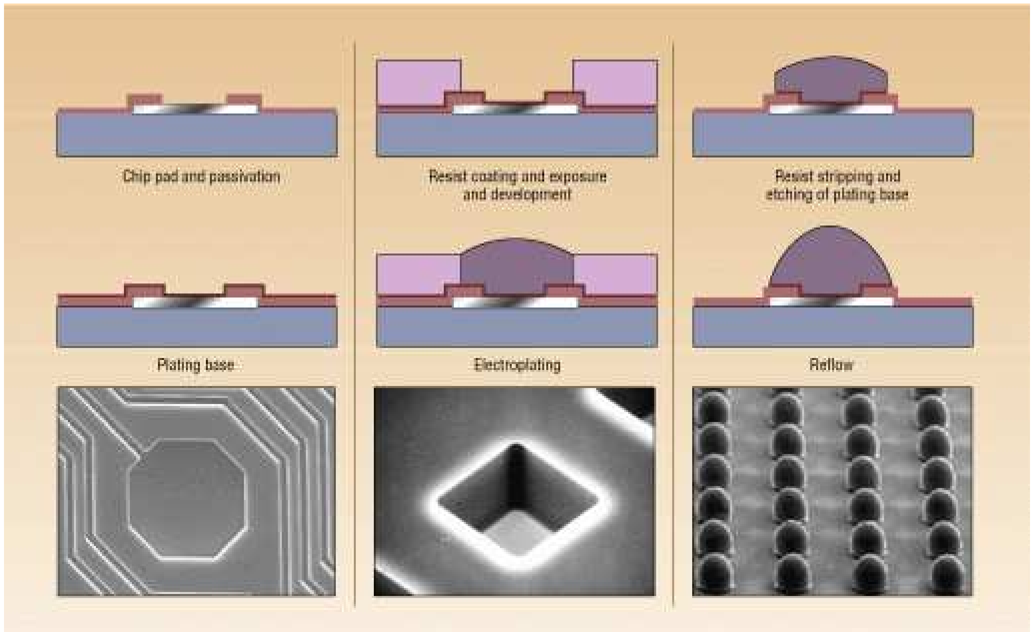




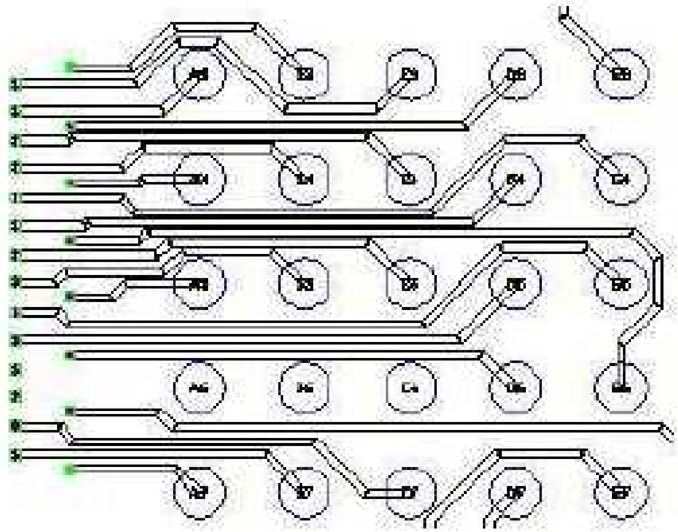


Redistribution Layer

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

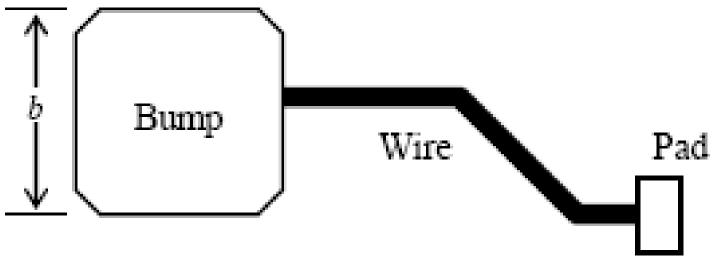


- RDL routing



Redistribution Layer (RDL) Routing Problem Formulation

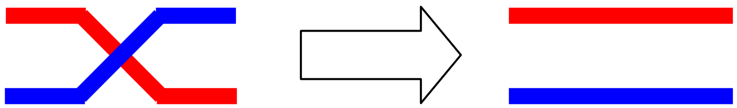
- Connect I/O pads to bumps



Given wire width

Minimum wire spacing

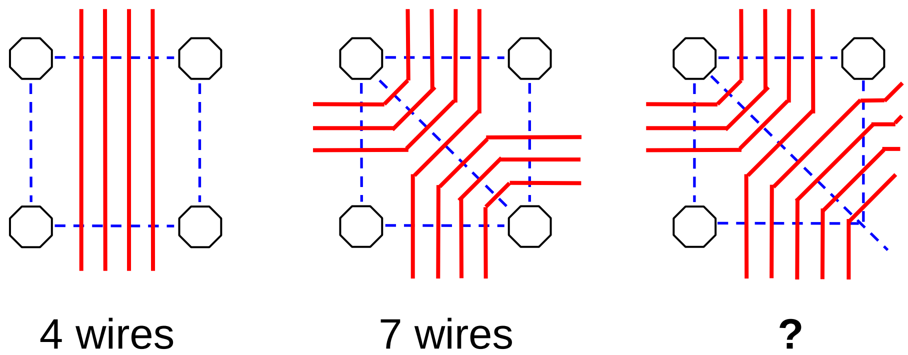
- Characteristics



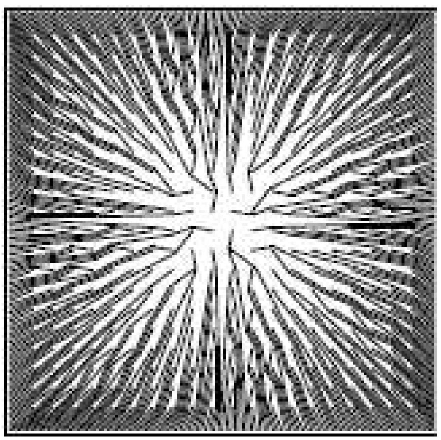
  - Interchangeability (no crossings)
  - 8-geometry wires are usually used (“ – | × ”) to reduce wire length and routing congestion

Previous Approaches

- Manual design
- Routing on graph models
  - Effective for Manhattan routing, but not for handling 45° wires

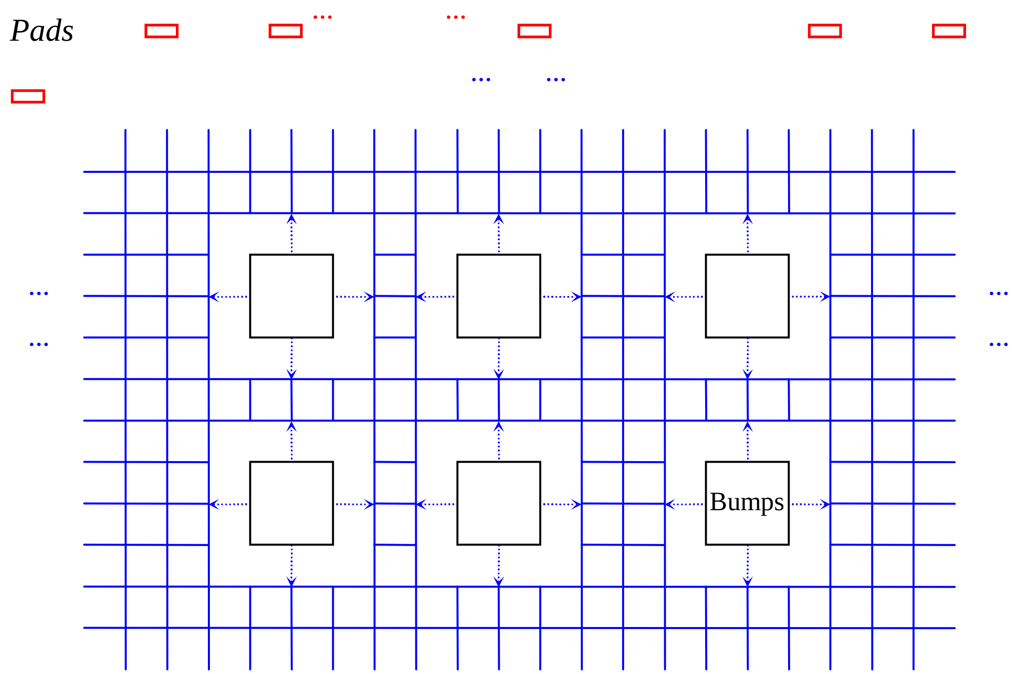


- Design for special patterns



Grid Network Approach

- Manhattan routing using a grid network
  - Construct a grid in the bump array
  - Routing solution ↔ network flow solution



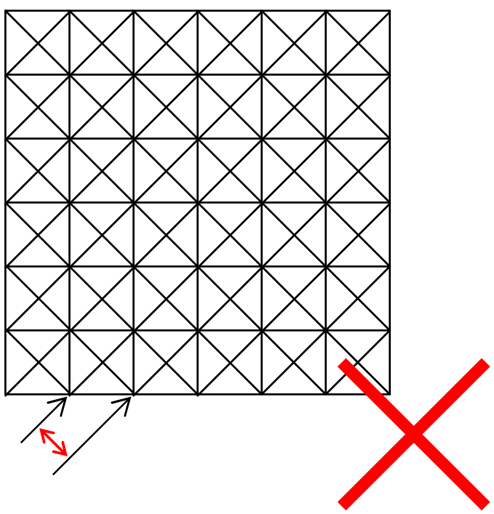
Unit size = wire width + spacing

Edge capacity = 1

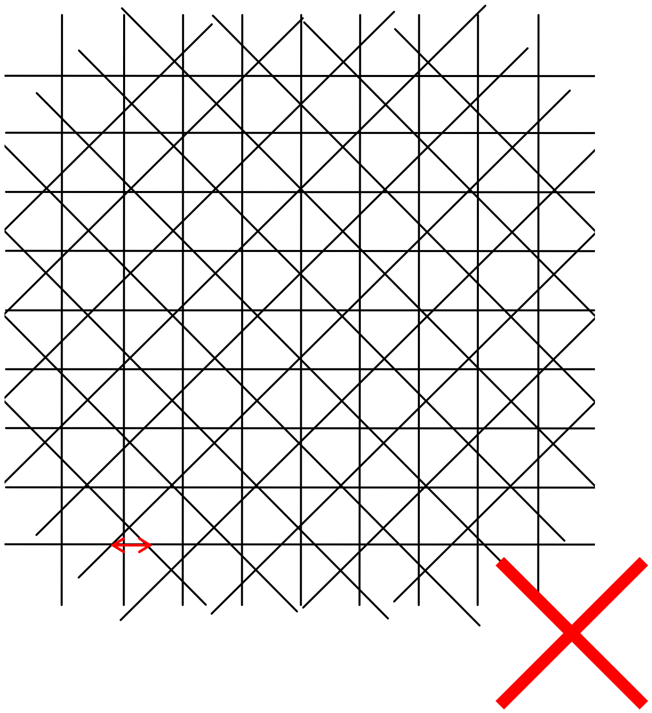
Vertex capacity= 1

Grid Network Approach

- Octilinear routing
  - Octilinear grid?



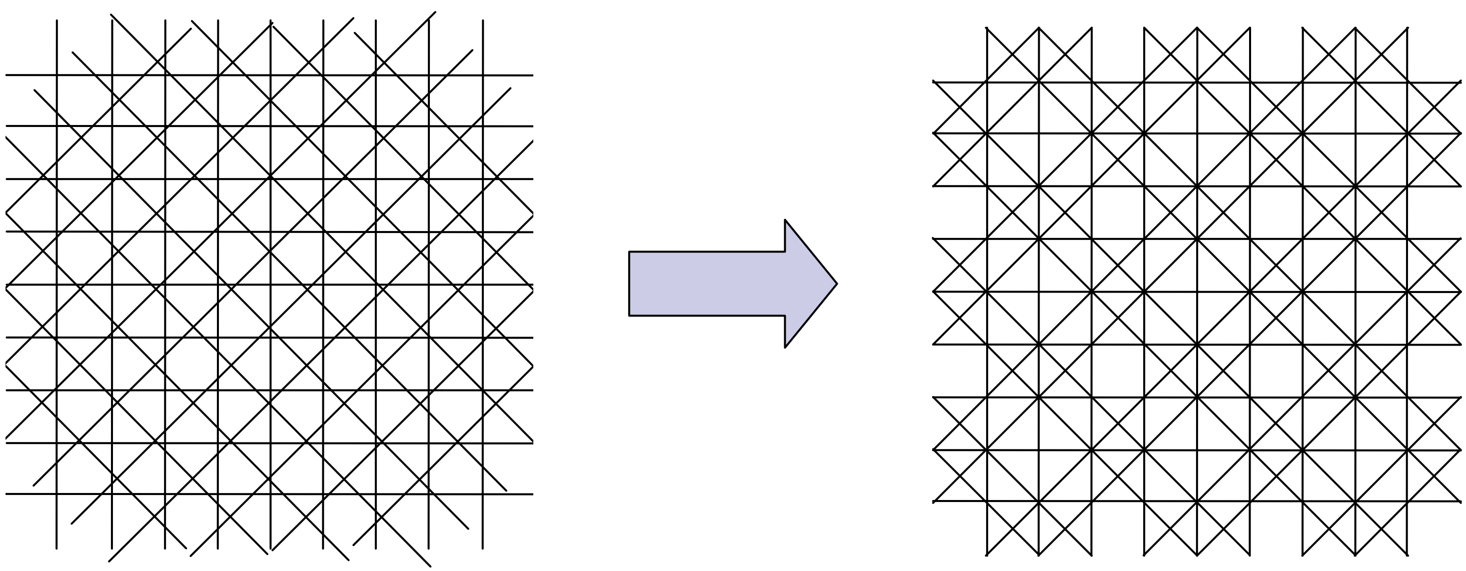
Not enough spacing between 45° tracks



Excessive crossing points

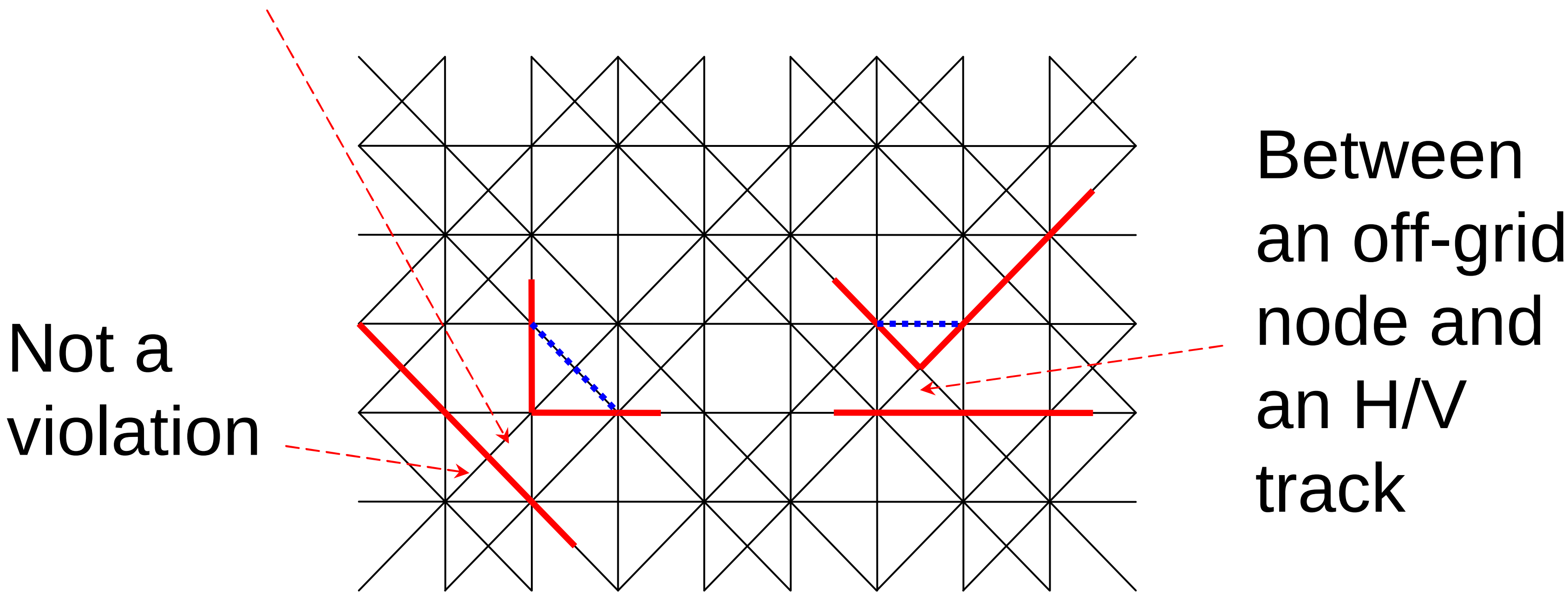
Octilinear Grid for RDL Routing

- Line shifting
  - Topologically shift the 45° tracks on to Manhattan grid
  - Preserve the actual positions of 45° tracks



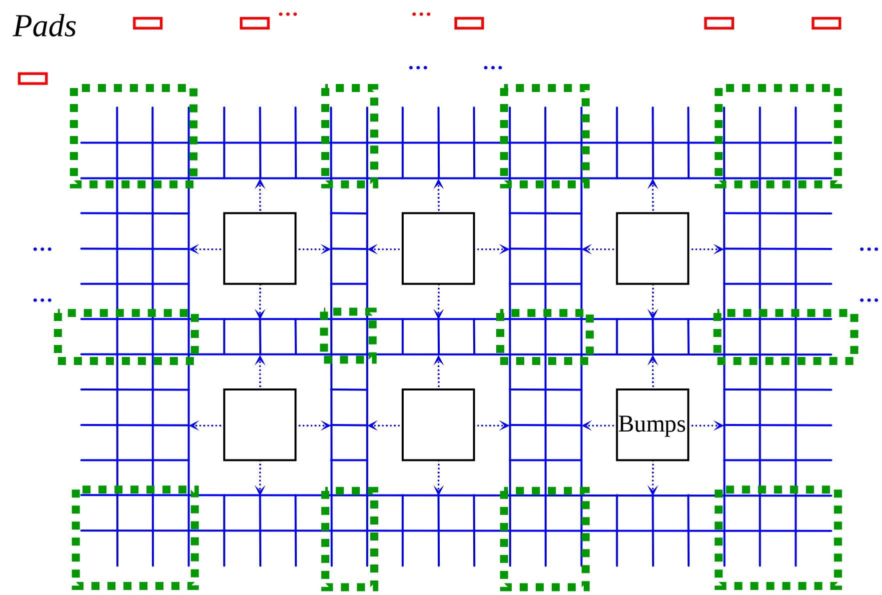
Octilinear Grid for RDL Routing

- Spacing violations avoided by min-cost max-flow on the grid
  - Between a grid node and a 45° track



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*



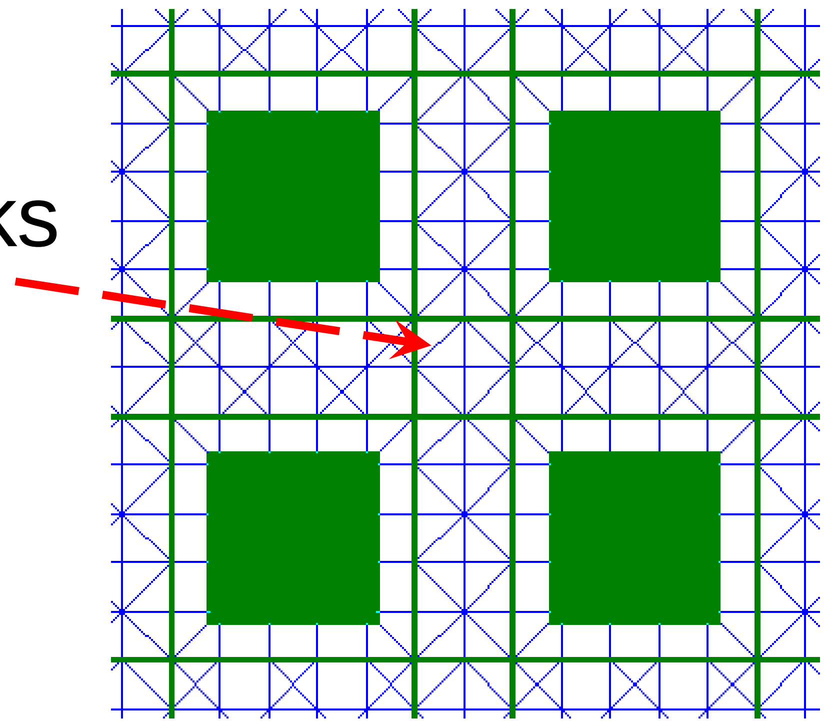
  - Routing solution ↔ network flow solution

Detailed Grid Construction

- Crossing area of H/V channels

$$C_{cross} = \left\lfloor \left((W_H + W_V) / \sqrt{2} - s \right) / (w + s) \right\rfloor$$

- (C_{cross} – 2) 45° tracks distributed at center
- Actual diagonal capacity = 4 →



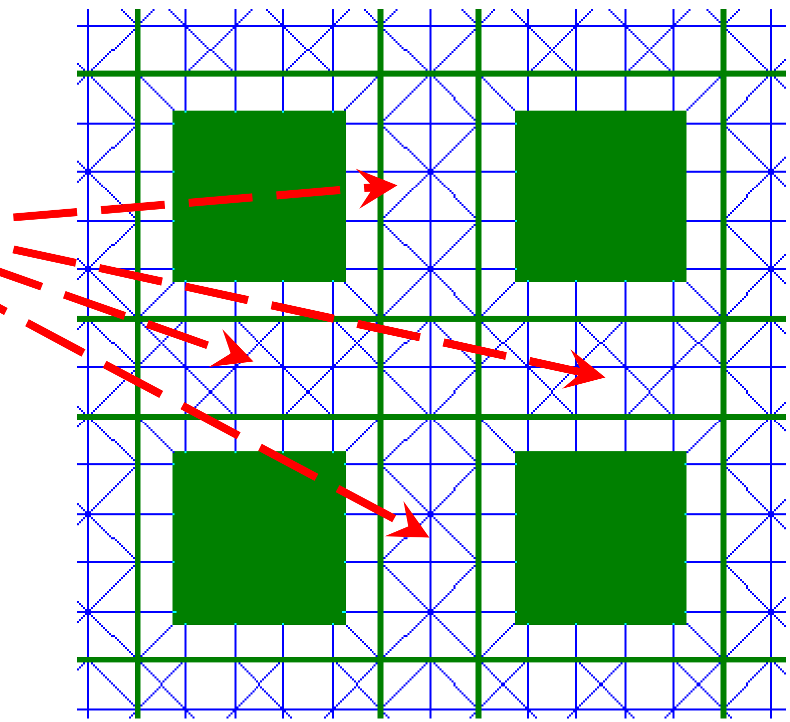
Detailed Grid Construction

- Channel segment area

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

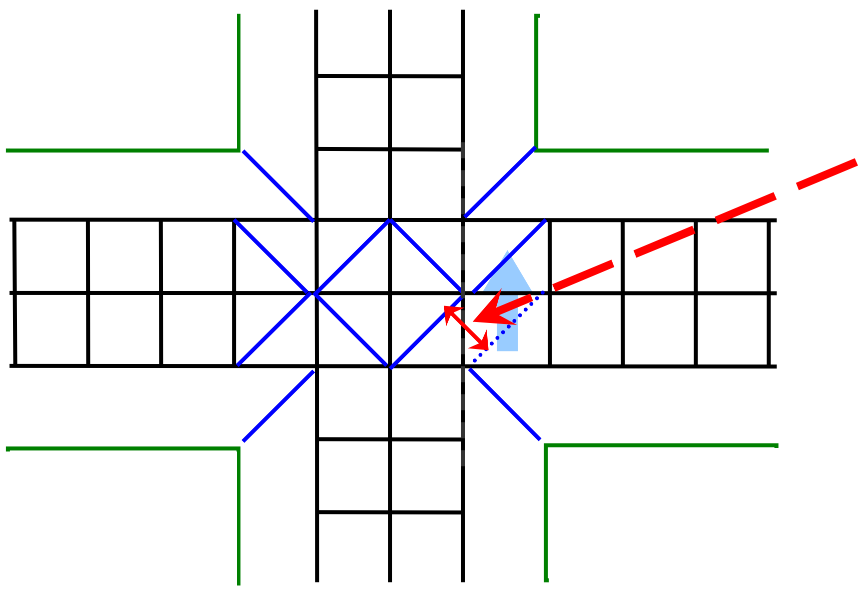
- $(C_{seg} - 1)$ 45° tracks distributed at center

- $C_{seg} = 4$ →



Detailed Grid Construction

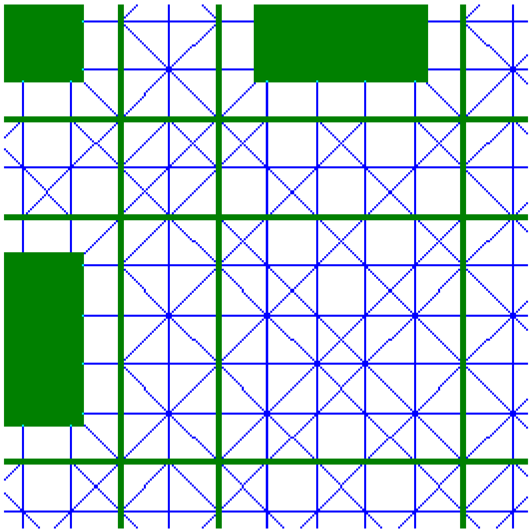
- On the boundary of 2 adjacent areas



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

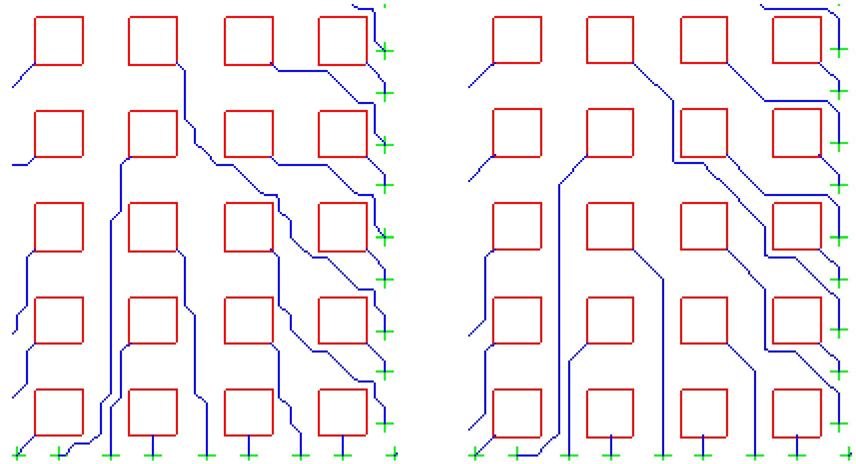
Detailed Grid Construction

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

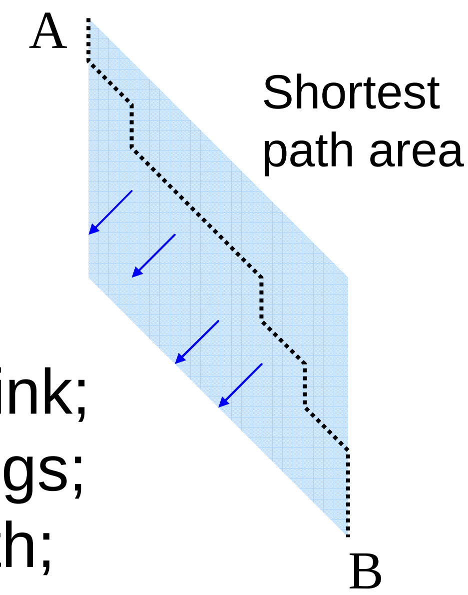


- Min-cost max-flow → RDL routing solution

Wire Smoothing



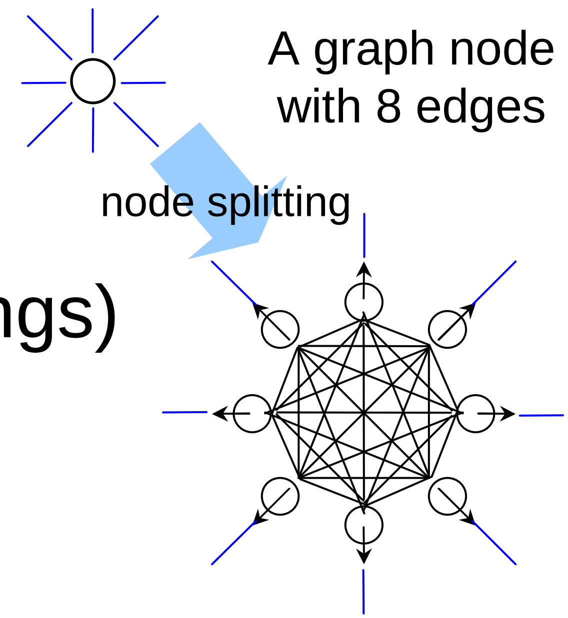
- Min-cost max-flow gives shortest paths
  - With possible zigzag shapes
- Iterative post processing



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

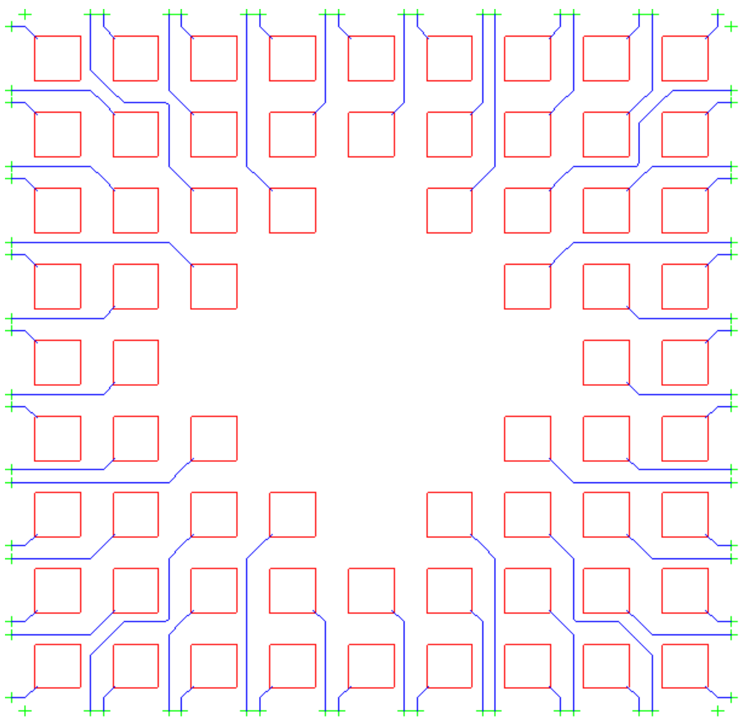
- Dynamic programming on Shortest path algorithm
  - “ α - β routing”, [Hu1985]
  - 1 node → 8 states
  - distance → (distance, #turnings)

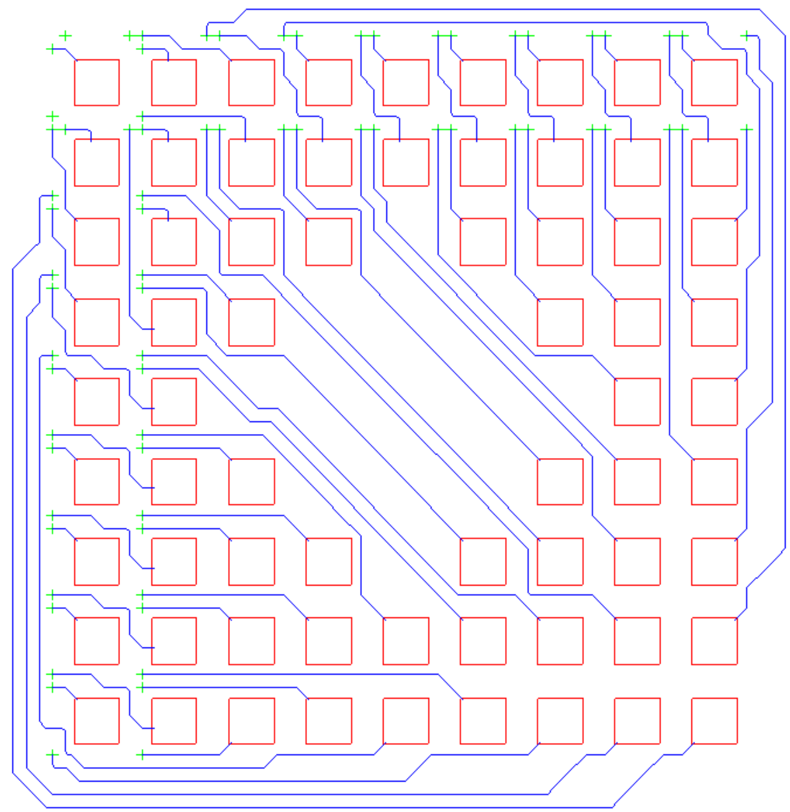


- O($n$log$n$) time

Experimental Results

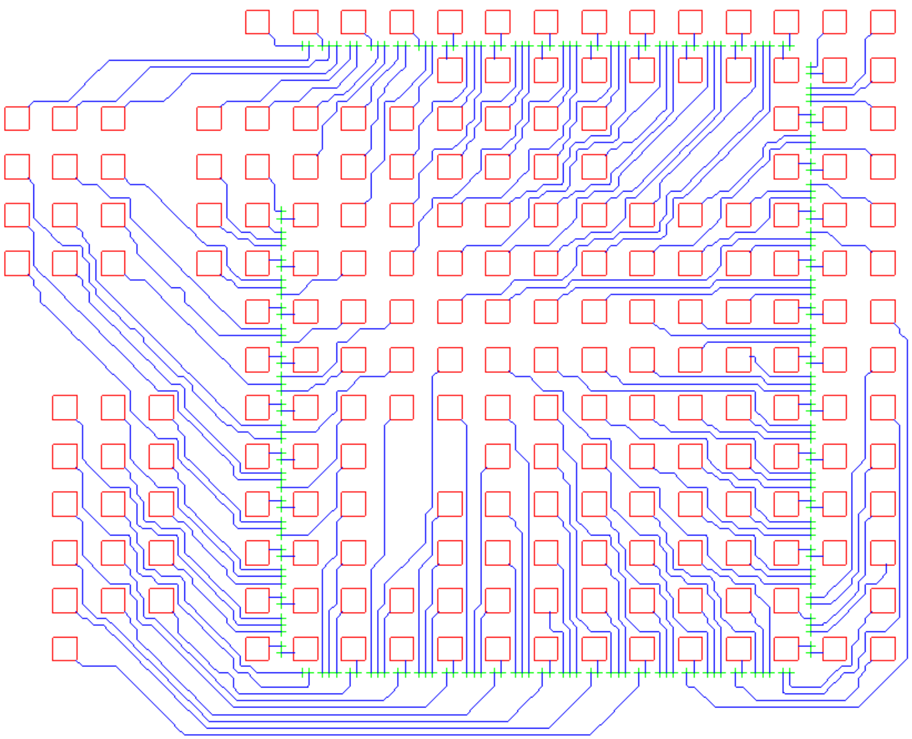
- Two different pad distributions in the same bump array

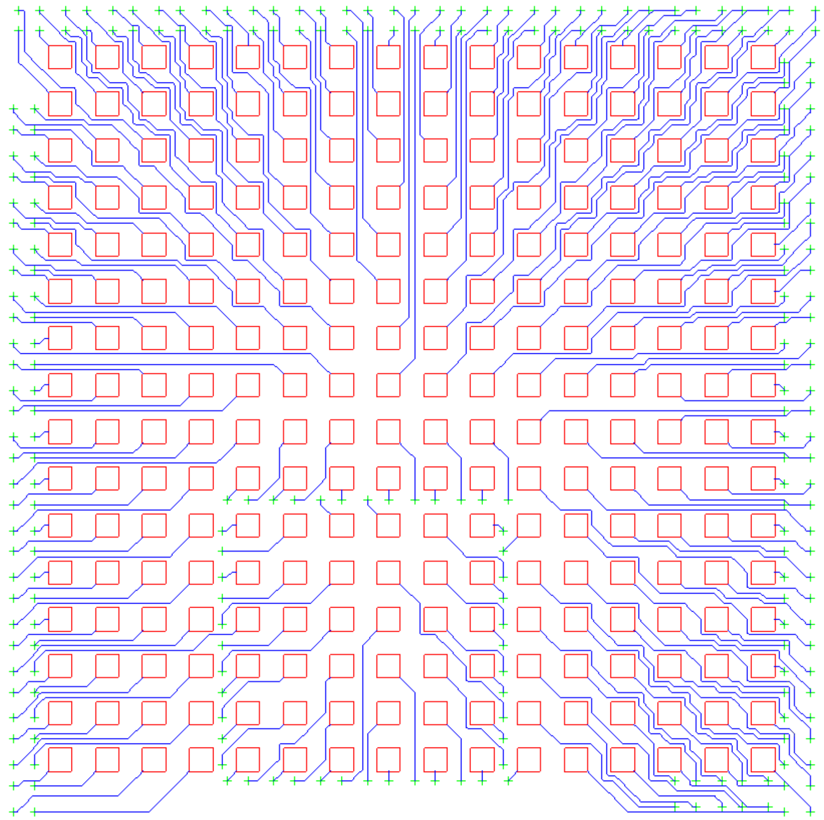




Experimental Results

- 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 ↑ & I/O connections ↑
  - Multiple redistribution layer

Q & A

- Thank you for your attention

This work is done in Mentor Graphics Corporation during an internship