Refined Single Trunk Tree: A Rectilinear Steiner Tree Generator for Interconnect Prediction

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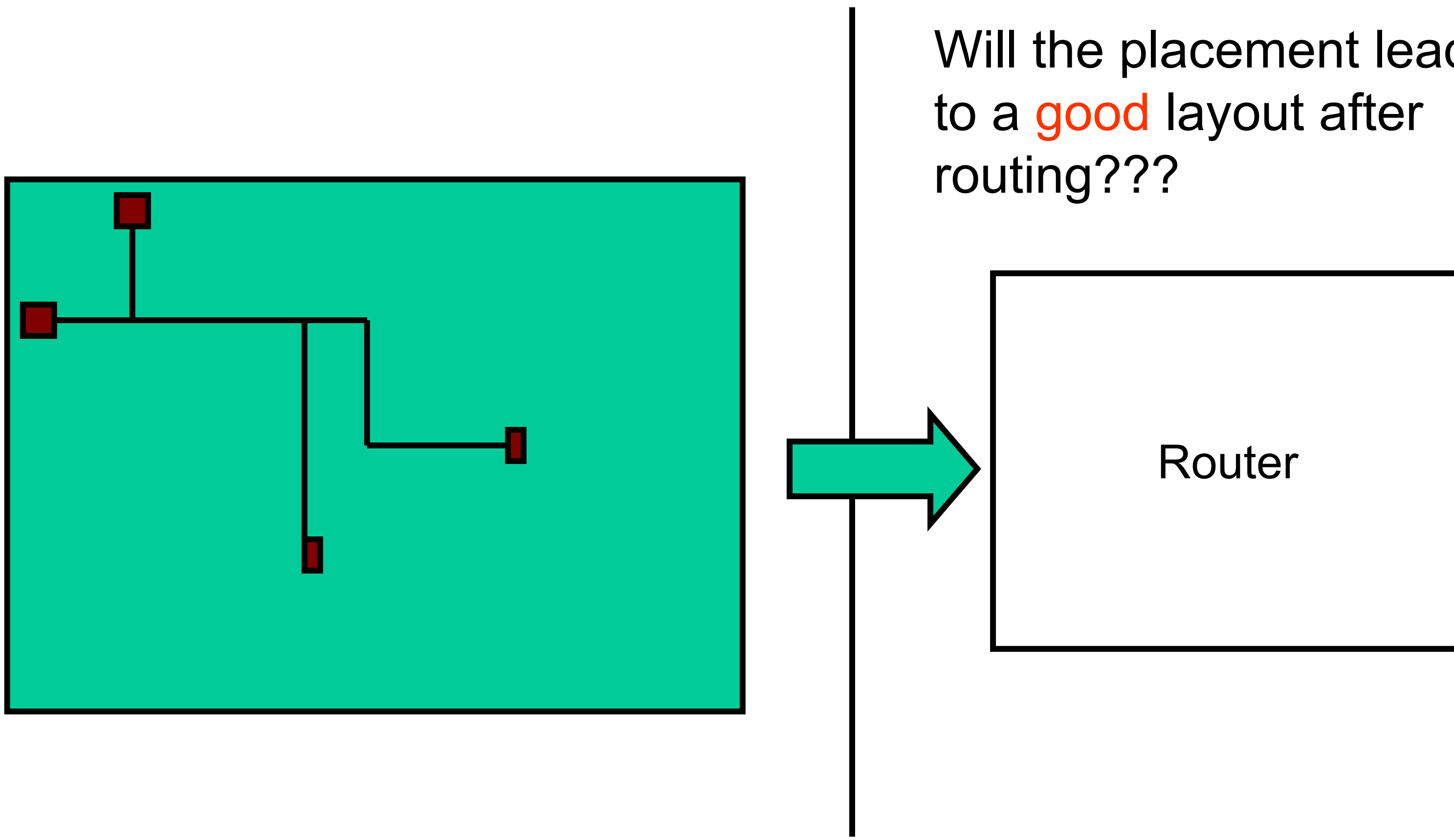
Outlines

- Background
- Algorithm Of RSTT (Refined Single Trunk Tree)
- Geometrical Properties of RSTT
- Experimental Results
- Conclusion and Future Directions

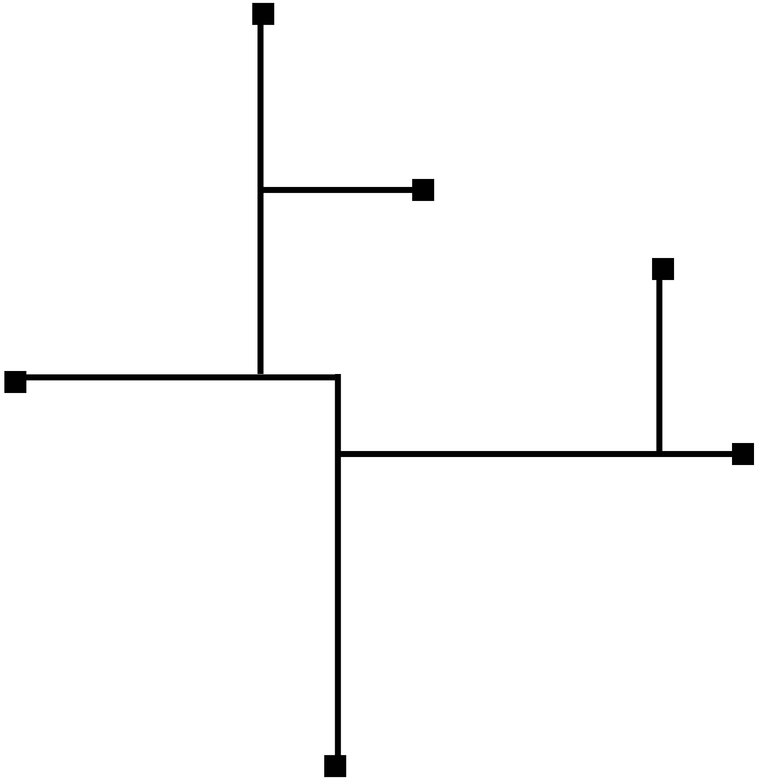
Measures of the Quality of a Placement



Difficult to Guess the Output of A Router

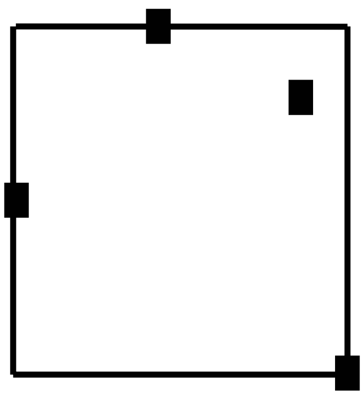
- Modern routers' behavior is extremely complex
- The routing results are router dependant
- Lack of interactions between placement and routing tools
- Routing is time-consuming

One Thing We Know

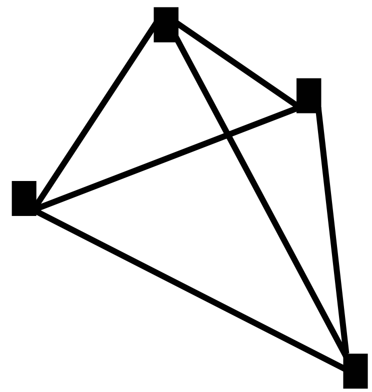


Desired feature of Routers: each net is routed as a Steiner Minimal Tree and with the timing in mind. (Short wirelength and small radius)

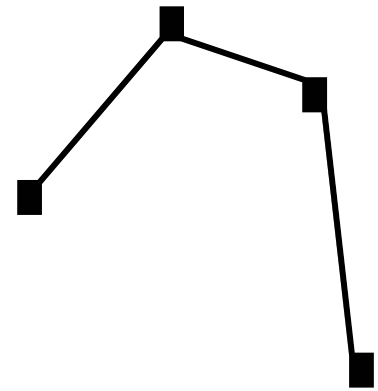
Steiner Tree Cost Estimators



(a) Bounding Box

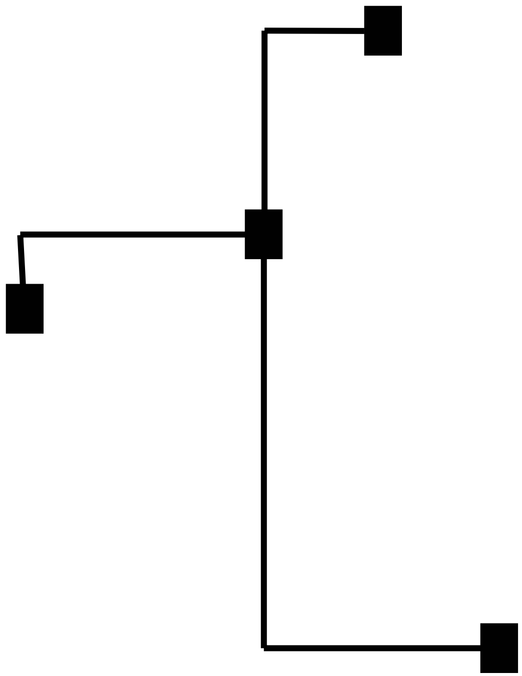


(b) Complete Graph



(c) Chain

Minimal Spanning Tree Based Constructive Prediction



Pros: Theoretical error bound cost(MST) < 1.5 cost (SMT);

Experimental results show error around 8% to 9%;

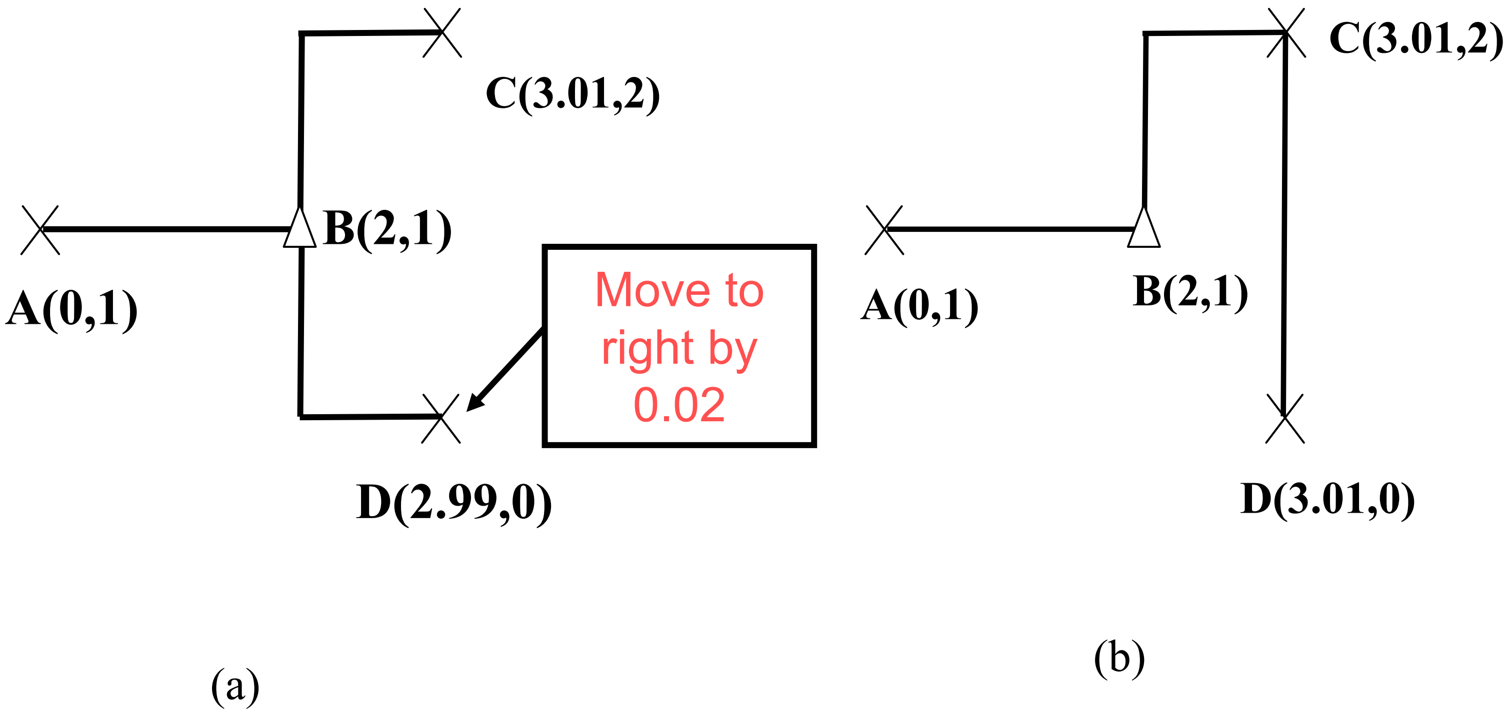
Lots of SMT heuristics are based on MST

Cons: O(nlogn) complexity with pretty big constant factor; topology sensitive to pins' locations

Runtime of MST Algorithm
(http://vlsicad.ucsd.edu/GSRC/bookshelf/Slots/RSMT/RMST/)

#terminals	O(n^2) Prim	Scheffer	Guibas-Stolfi
5	0.000006	0.000400	0.000053
10	0.000024	0.000685	0.000138
50	0.000567	0.003601	0.001118
100	0.002269	0.007959	0.002613
500	0.055323	0.051744	0.017536
1000	0.223079	0.118234	0.038819
5000	5.774400	0.889230	0.243520
10000	23.641100	2.477000	0.531860
50000	N/A	22.685750	3.461500
100000	N/A	75.654200	9.253000
500000	N/A	486.621200	91.634800

MST's unstable topology

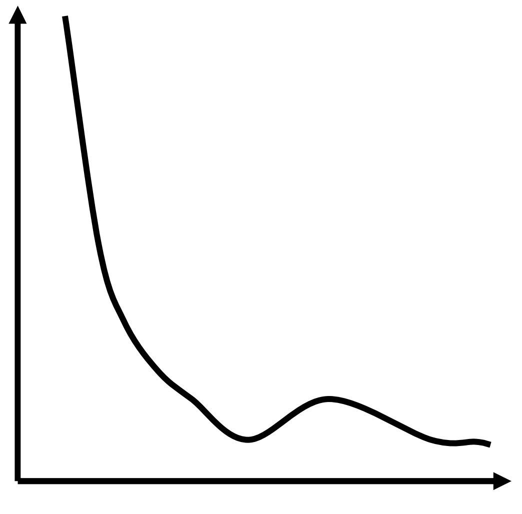


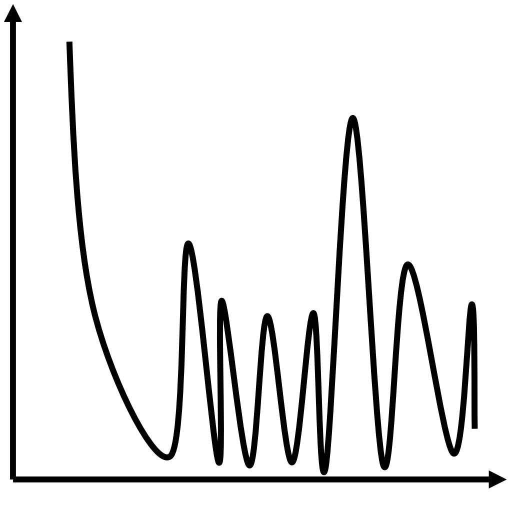
An example of MST for two 4 pins nets, small perturbation on pin's location results dramatically change on topology

Requirement for Stable topology

•Interconnect Prediction provides cost function for other optimization algorithm (placement, floorplanning tools);

•Smoother cost surface can make the optimization algorithm converge fast, produce better solution.





Expectation to Steiner tree Generator used in Routing Estimation

- Fast

  Near Linear Complexity, Easy to do incremental computation.

- Wirelength close to SMT

  (Lumped Capacitance)

- Bounded radius (Resistance)
- Stability

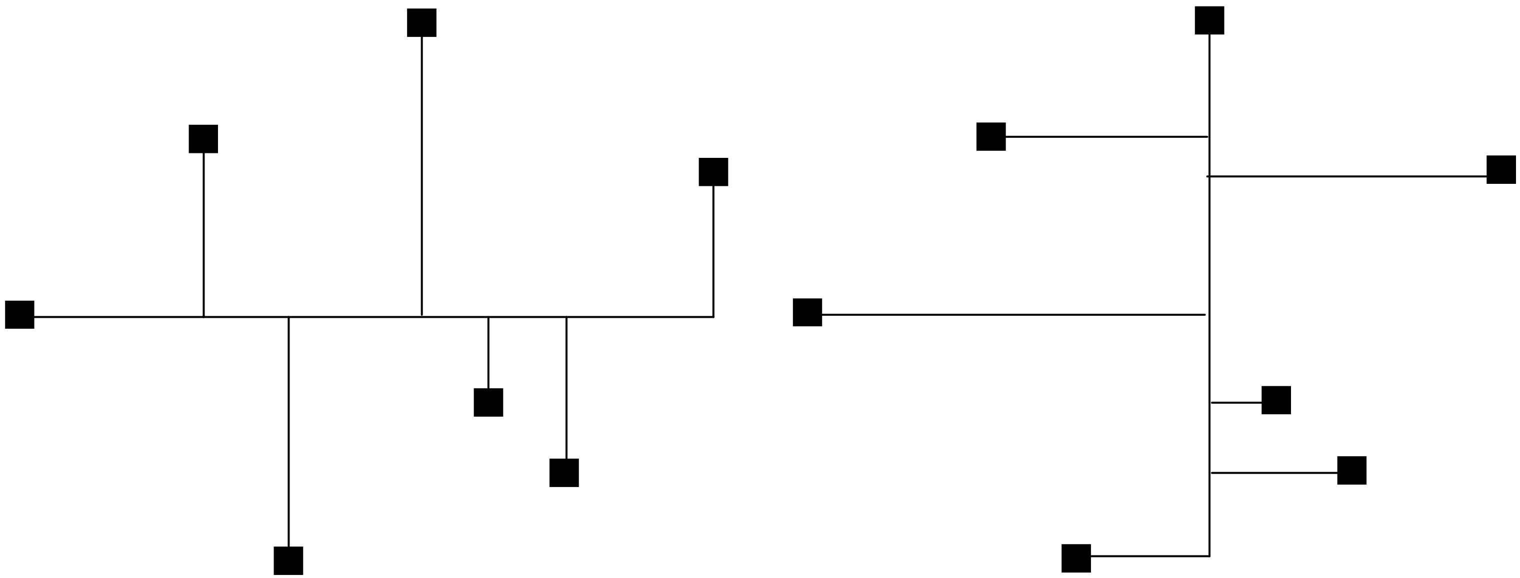
Delay = r X c

Single Trunk Tree

(www.ucmp.berkeley.edu/IB181/VPL/Lyco/Lyco2.html)

- Trees which produce single vertical branches at or near soil level
- Hierarchical, from any leaf to root, only need several hops
- Efficiently connect thousands of leaves together
- Hint: Why not restrict the number of hops in the routing tree

Single-Trunk Steiner Tree



(a) STST with horizontal trunk

(b) STST with vertical trunk

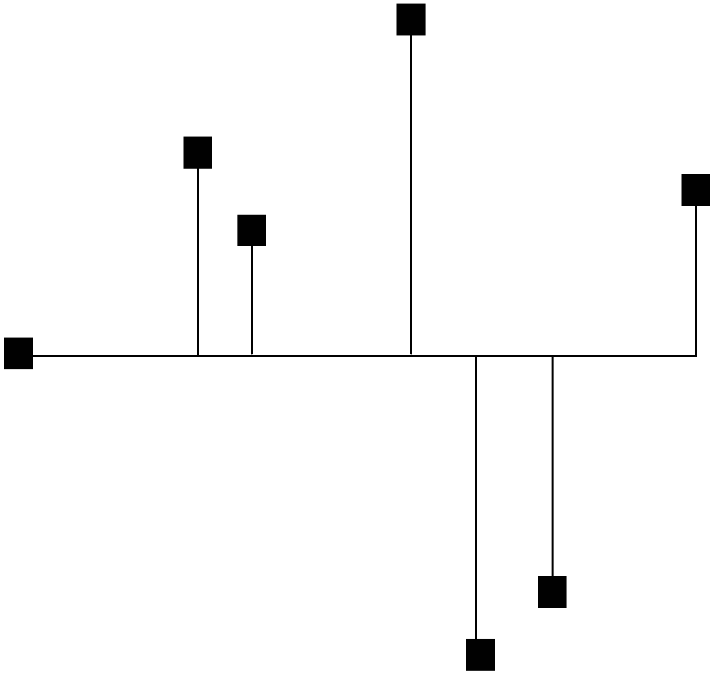
Pros and Cons of STST

- Pros:
  - Easy to construct: O(n) complexity
  - Bounded source to sink distance
  - Stable topology
  - Wire length is close to SMT for nets with less than 5 pins. For 3 pins nets, STST is the optimal SMT.
- Cons:

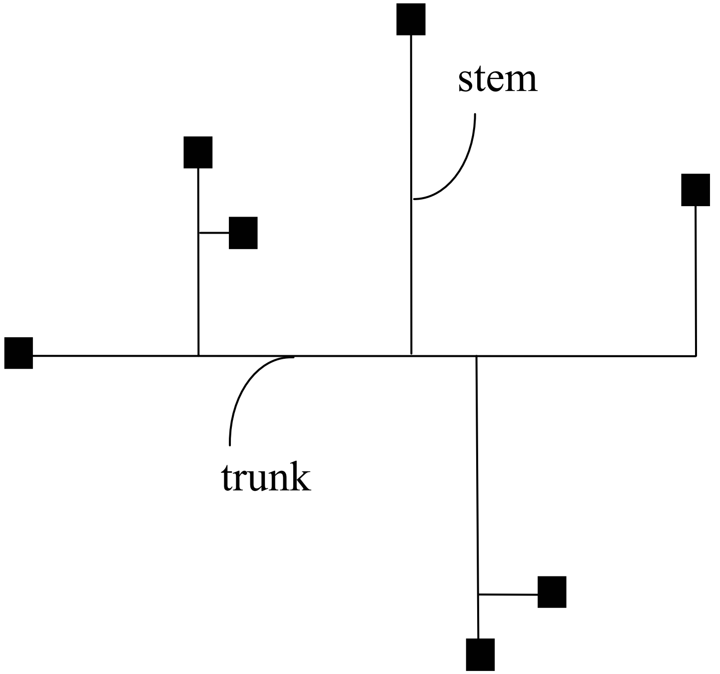
  Huge error for Big net (more than 5 pins)

  O(n) growth rate of wirelength, while SMT's is $O(n^{0.5})$

Refined Single Trunk Tree



(a) STST



(b) RST-T

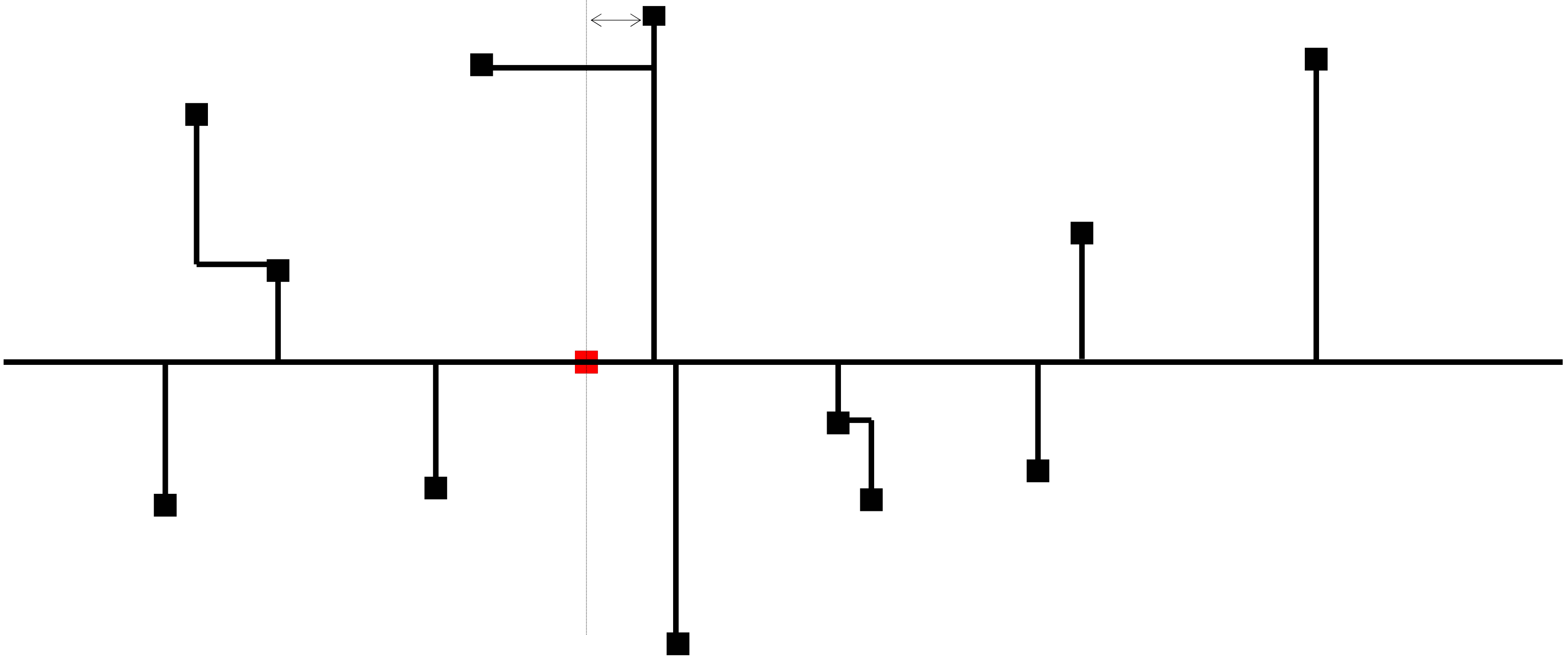
Refined Single Trunk Tree Algorithm

A. Construct a RST-T with horizontal trunk
   1. Determine the trunk position
   2. Process all the points on the upper half plane
      1. Select the first stem (The point with smallest x distance to the pin on the trunk)
      2. Process all the points to the left of first stem from right to left
      3. Process all the points to the right of first stem from left to right
   3. Process all the points on the lower half plane
   4. Postprocessing on left most point and right most point of the trunk

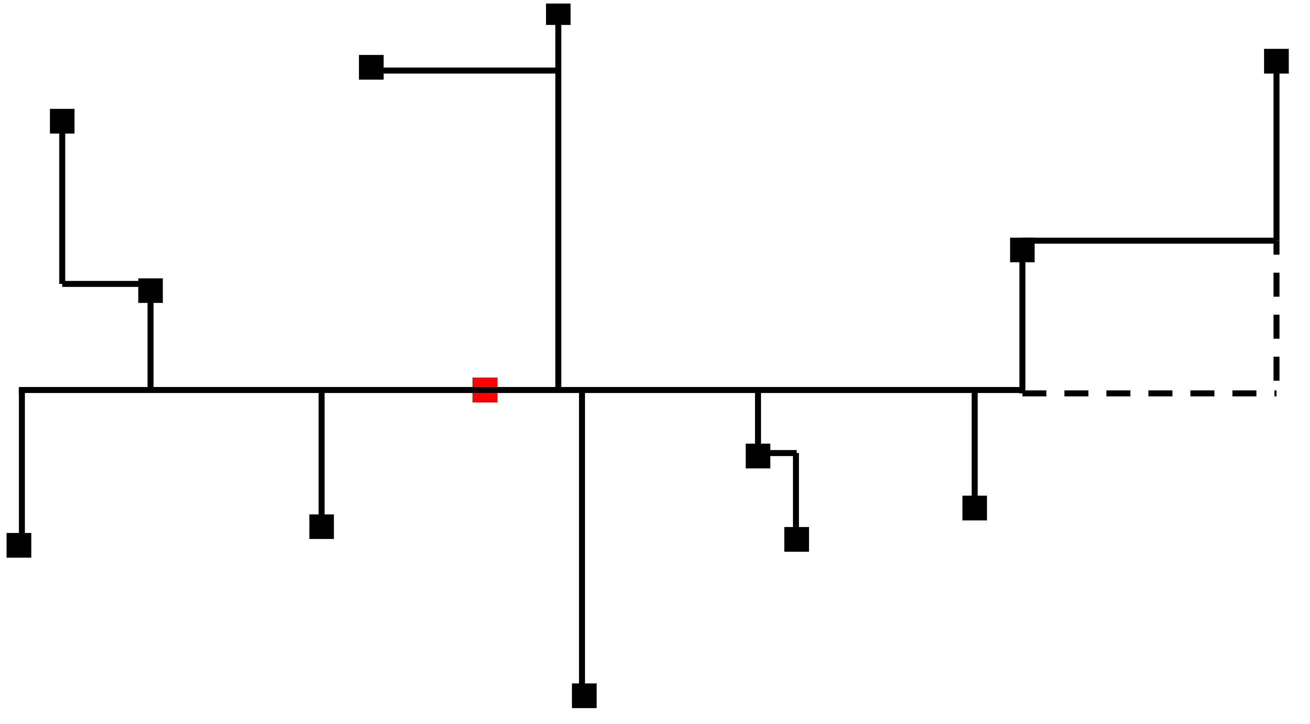
B. Construct a RST-T with vertical trunk

C. Return a routing tree with shorter wirelength

Example of RST-T Algorithm



Example of RST-T Algorithm (Post Processing)



Geometrical Properties of RSTT: Wirelength

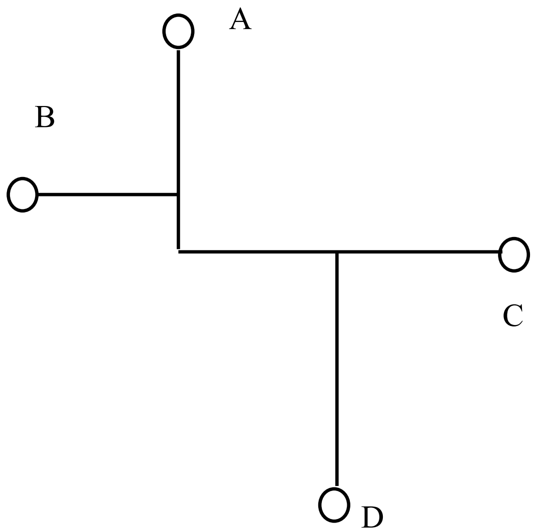
- Lemma 1: Assuming all the pins are randomly distributed in a unit square with uniform distribution, the expected wire length for RST-T is $O(\sqrt{n})$, where, n is the number of pins.

Reason: when $n \to \infty$

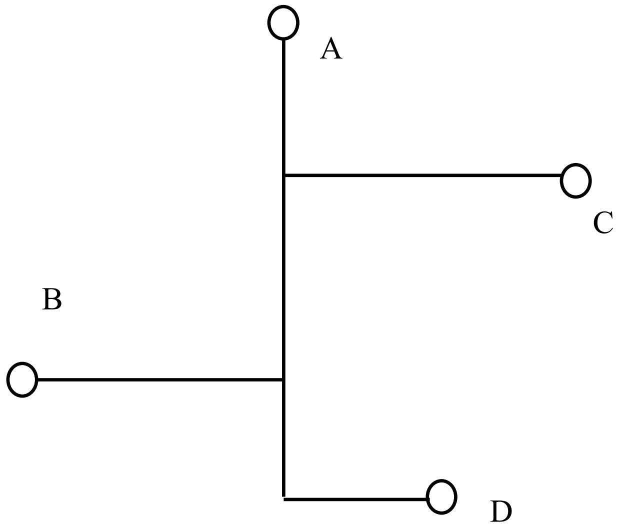
The expected cost to connect each pin to its neighboring stem is $o(n^{-0.5})$

Geometrical Properties of RST-T: Wirelength

- Lemma 2: For a net with no more than 4 pins, RST-T is an SMT.

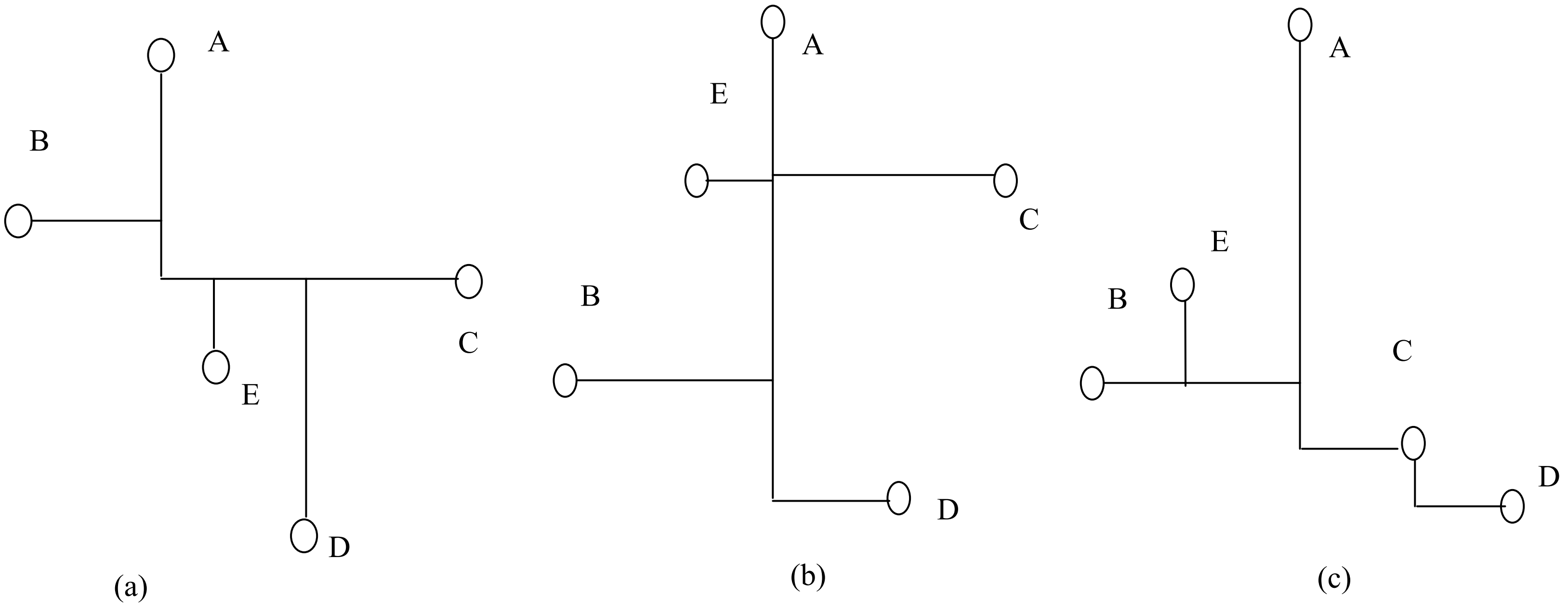


(a)



(b)

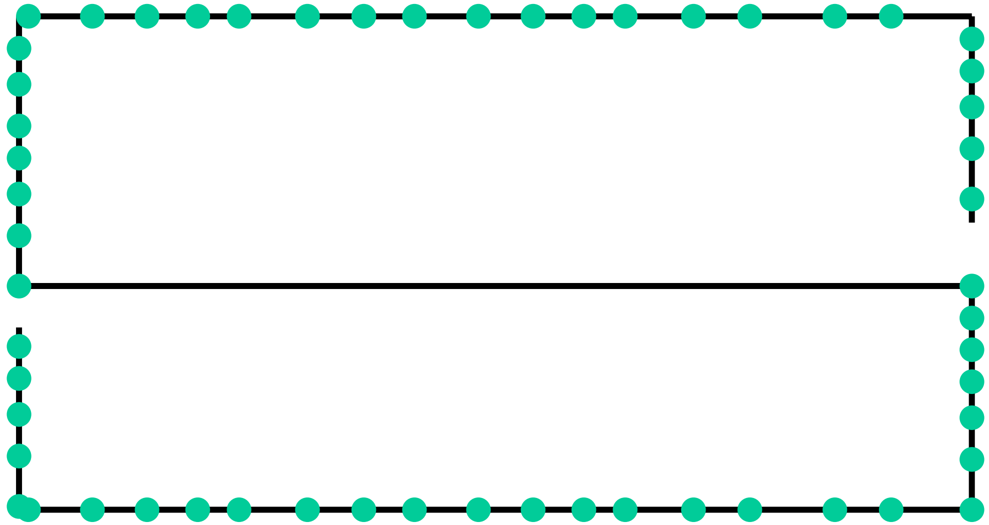
Experimental Result: RST-T is optimal SMT for 5 pins net



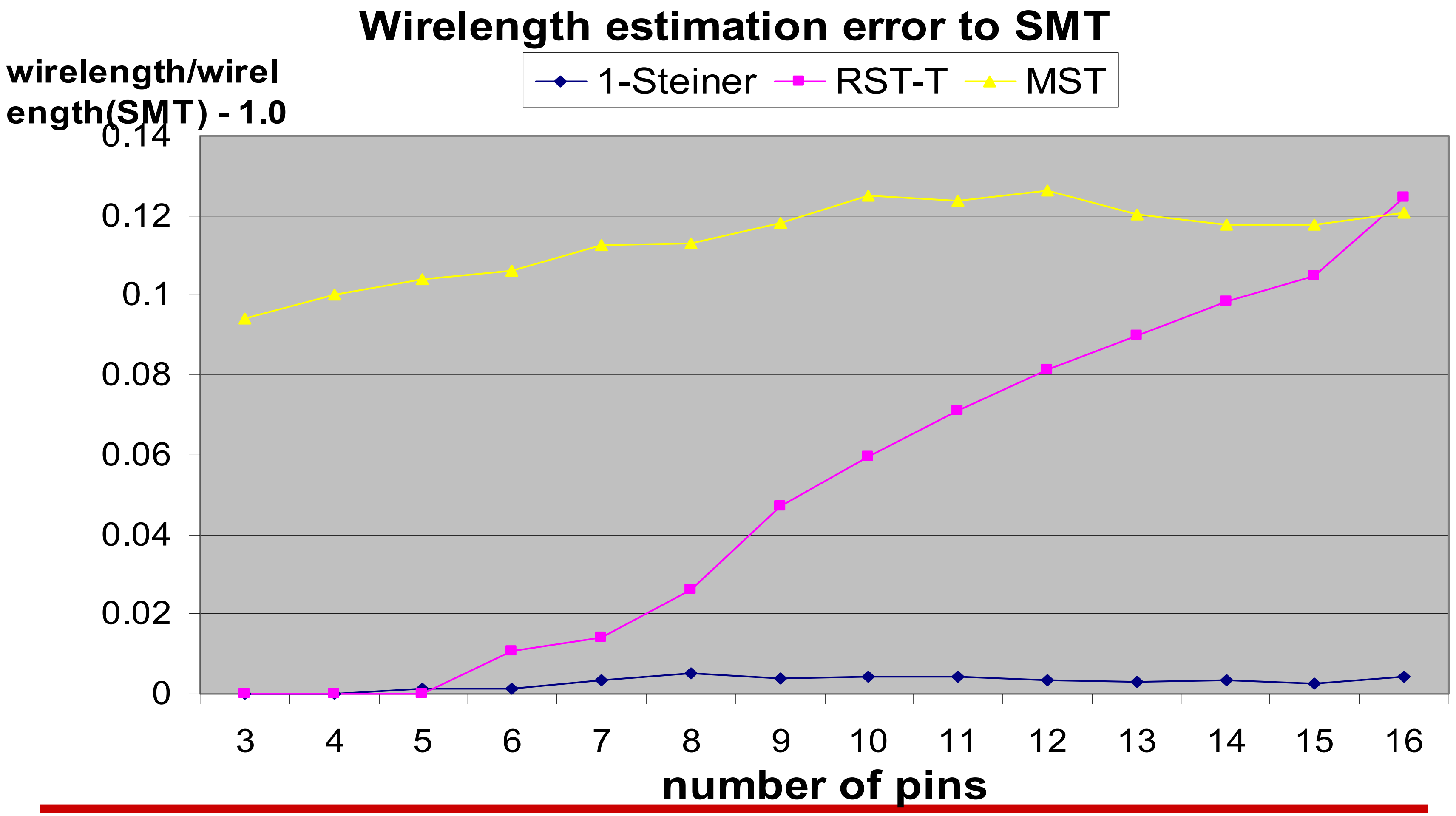
Three possible RST-T topologies on five points

Geometrical Properties of RSTT: Radius

- Lemma 3: Assume the net has a bounding box with width w and height h, RST-T radius is bounded by $max\{3w+2h, 3h+2w\}$.



Experimental Results: Wirelength



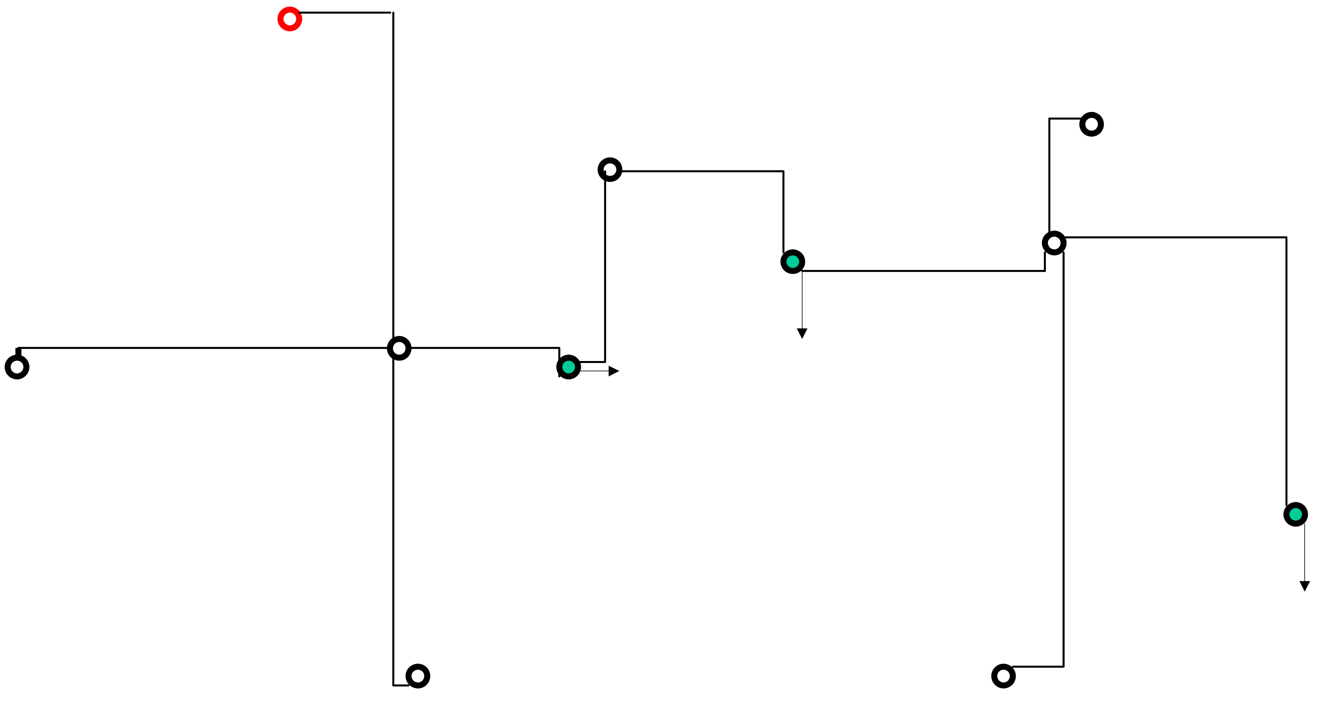
Experimental Result: Runtime

#pins	SMT	1-Steiner	MST	RST-T
3	2.1e-4	1.1e-4	8.0e-6	7.5e-7
5	4.2e-4	2.0e-4	1.7e-5	7.8e-7
7	9.3e-4	2.4e-4	2.8e-5	8.0e-7
9	2.2e-3	3.2e-4	3.7e-5	8.4e-7
10	3.2e-3	3.8e-4	4.4e-5	8.5e-7
13	1.2e-2	5.9e-4	6.3e-5	9.4e-7
16	5.2e-2	8.2e-4	9.3e-5	1.6e-7
20	8.8e-1	9.4e-2	1.6e-4	2.2e-6

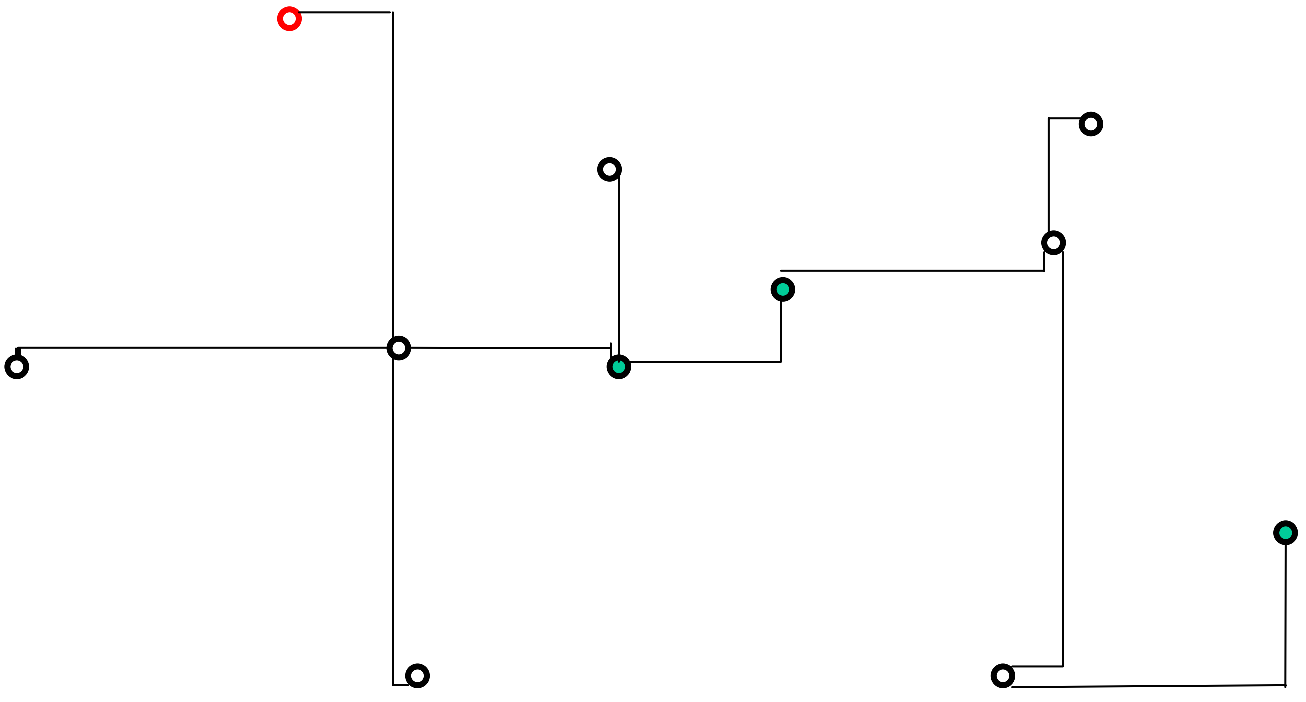
Experimental Settings for Stability Test

- We test the stabilities of different algorithms on a set of 10-pin nets
- Test cases are generated from a uniform distribution on a 1000 by 1000 grid
- Randomly select 1 pin as source, others as sinks
- Randomly select 3 pins and perturb their locations by 10
- Statistics on the changes of source-to-sink distance for each sink

Experimental Results: Stability (Examples)



Experimental Results: Stability (Examples)



Experimental Results: Stability

# of pins	SMT (Exact)	1-Steiner	MST	RSTT
Mean change.	77	46	139	9
Std div. Of change	0.146	0.113	0.217	0.0536
Max Change	237	193	393	39

Conclusion and Future Directions

- RST-T displays several advantages for Steiner cost estimation:
  - Easy to construct
  - Wirelength close to SMT for typical VLSI net
  - Bounded source-to-sink distance
  - Topology not sensitive to pins' locations
- Future Directions
  - How to deal with obstacles?
  - Can we get more hierarchies?