On Optimum Designs of Universal Switch Blocks

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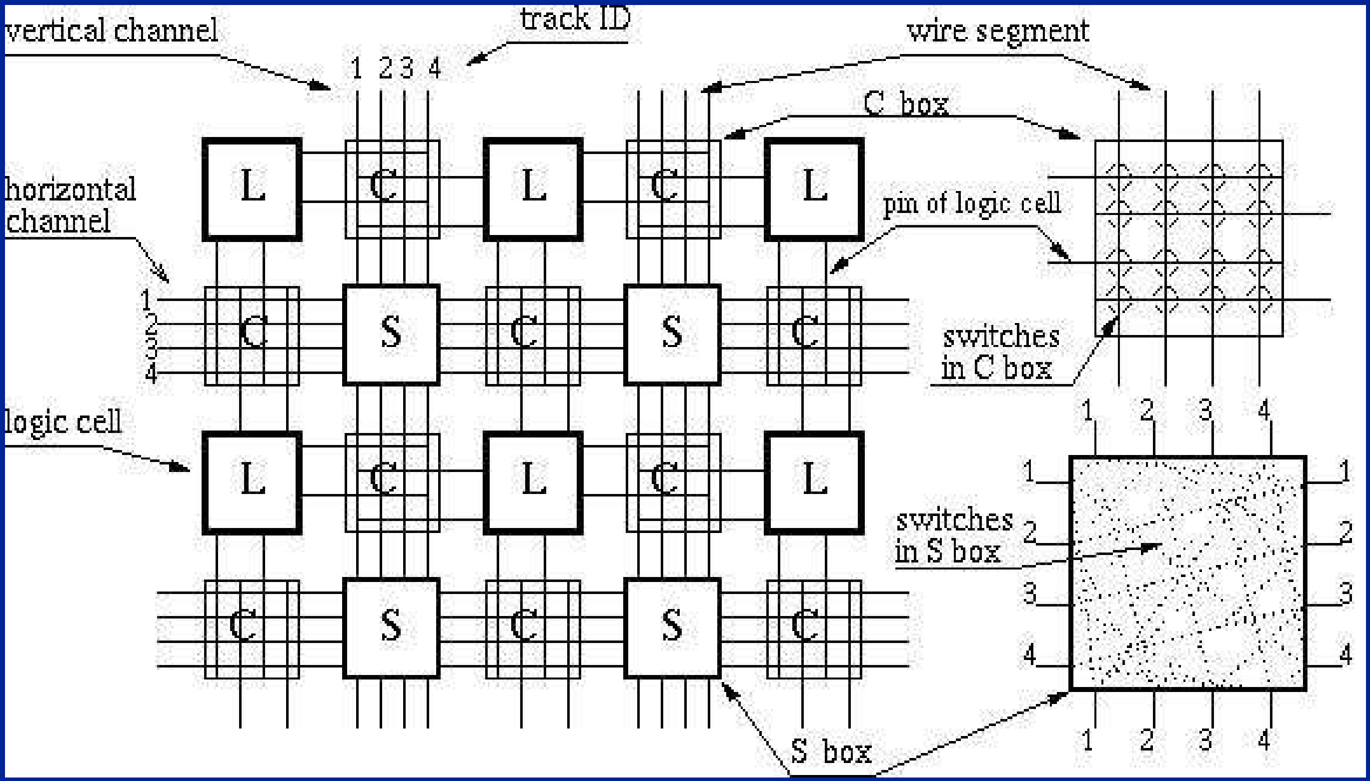
Outline

- Background
- Routing requirement modeling
- Graph models for switch box
- Universal Switch box design problem
  - 2D FPGA
  - Generic USB
- Decomposition theorem
- The Design scheme for Basic USBs
- Experimental results on the Optimum USBs
- Conclusion

Switch box design problem in 2D-FPGA



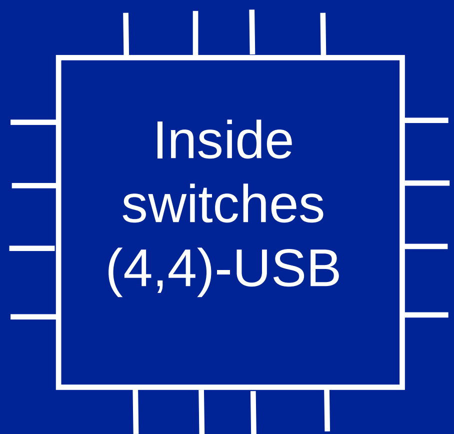
Design Goal: **to find Switch Boxes (SB) with higher routability and fewer switches.**

Previous Works

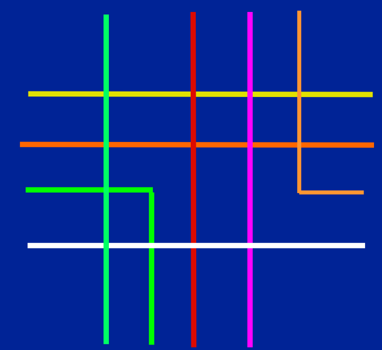
1. Flexibility, Probability model
   (by J. Rose and S. Brown)
   Flexibility, average probability of completing a connection
2. Universal Switch Block (USB)
   (by Y.W. Chang, D.F. Wong, C.K. Wong)
   a symmetric design and routable for every set of 2-pin nets routing requirement
3. Generic Universal Switch Block
   (by M. Shyu, G.M. Wu, Y.D. Chang, Y.W. Chang)
   a generalized design and claimed to be routable for every set of 2-pin nets routing requirement
4. Comment on Generic Universal Switch Block
   (by H.B. Fan, Y.L. Wu, Y.W. Chang)
   Proved the generalized symmetric switch blocks are not universal for odd $W \geq 3$ when $k \geq 7$.
5. This paper continues on the unsolved part of the USB problem.

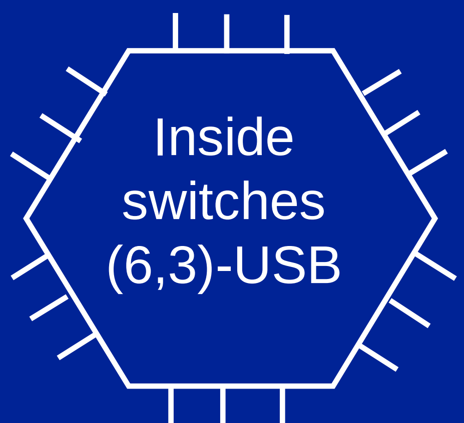
Generic (k, w)-USB :

the USB of k-way and W terminals on each way

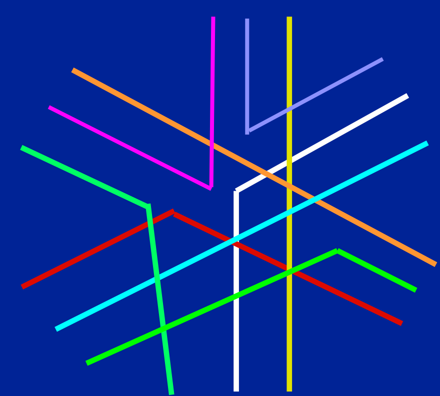


routable for every
(4,4)-routing
requirement



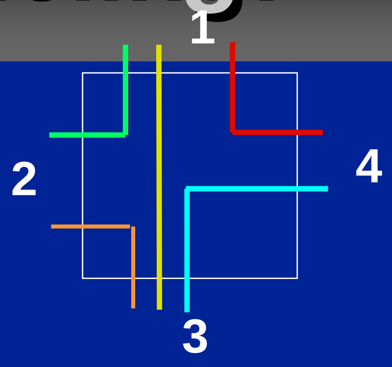


routable for every
(6,3)-routing
requirement



Routing Requirement Modeling:

For (4, w)-SB, label the sides *1, 2, 3, 4*.



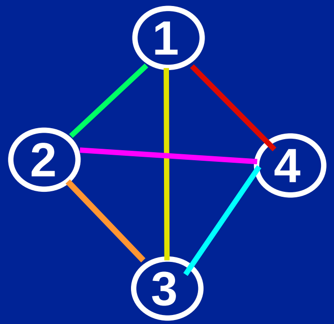
A net <=> a subset of {1, … , 4}
Routing requirement <=>collection of subsets
Global Routing (GR)

{1, 2} {3, 4} {2, 3}
{1, 3} {1, 4}

Balanced Global Routing, (4, w)- GR

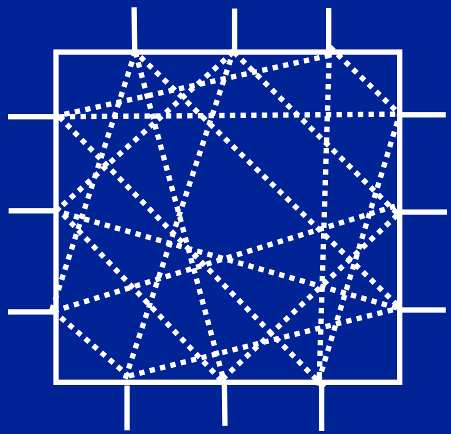
{1, 2} {3, 4} {2, 3}
{1, 3} {1, 4} {2, 4}

W - regular graph

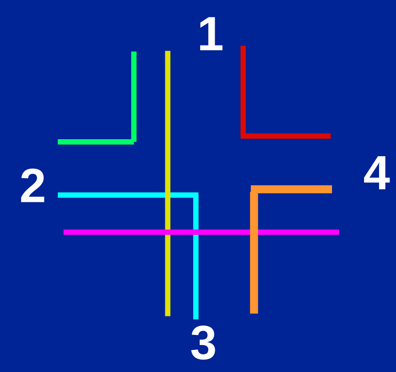


Graph Model of Switch Boxes

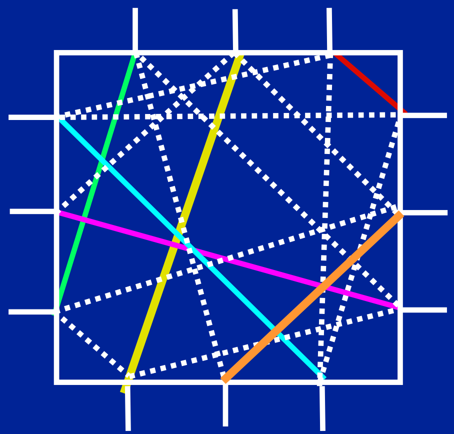
- **(k, W) - SB <=>** graph: terminals as nodes; switch as edges
- **A detailed routing <=>** a spanning forest



A (4, 3) - USB view as a graph



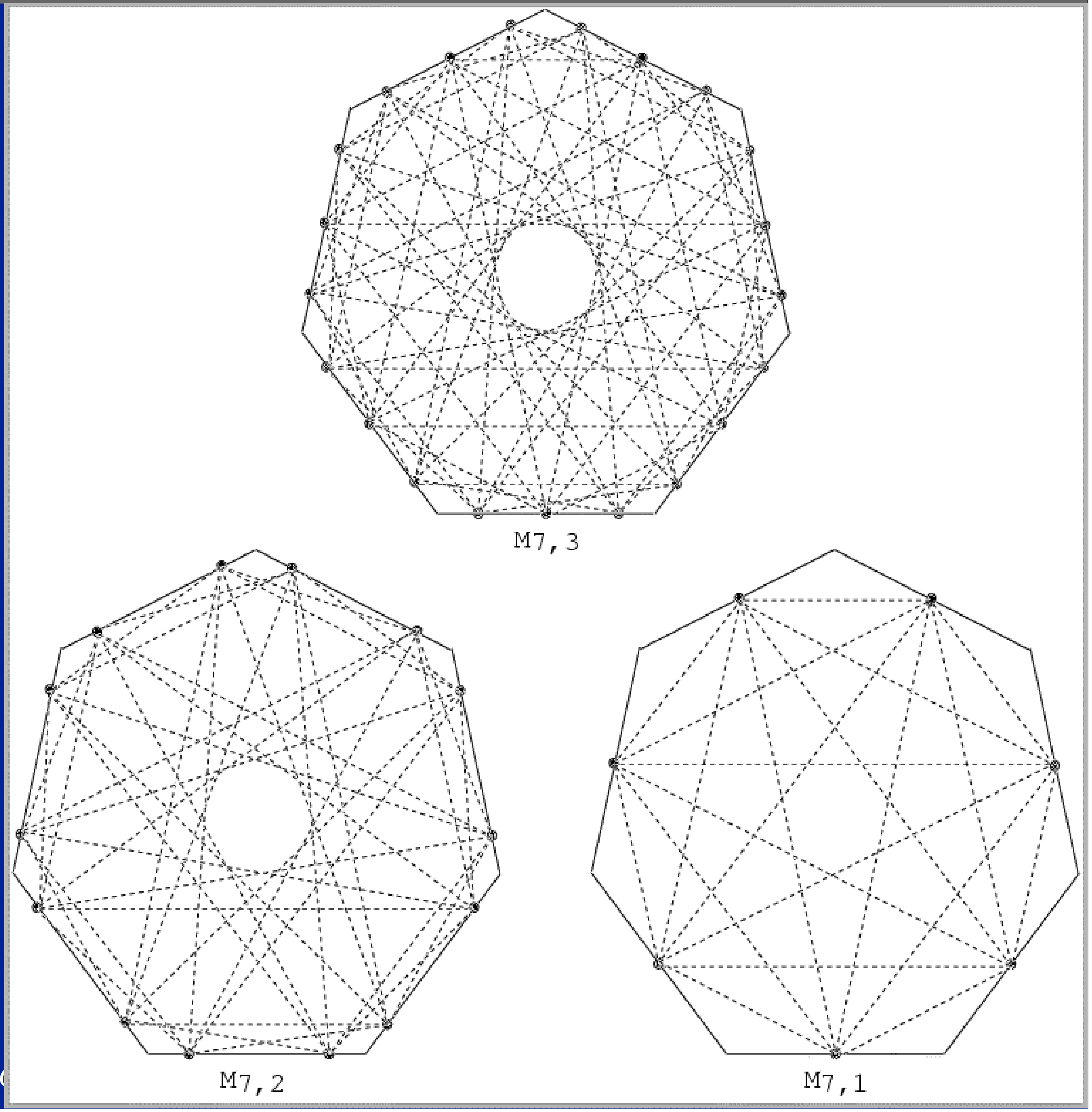
A (4, 3) - GR



A detailed routing as a spanning forest

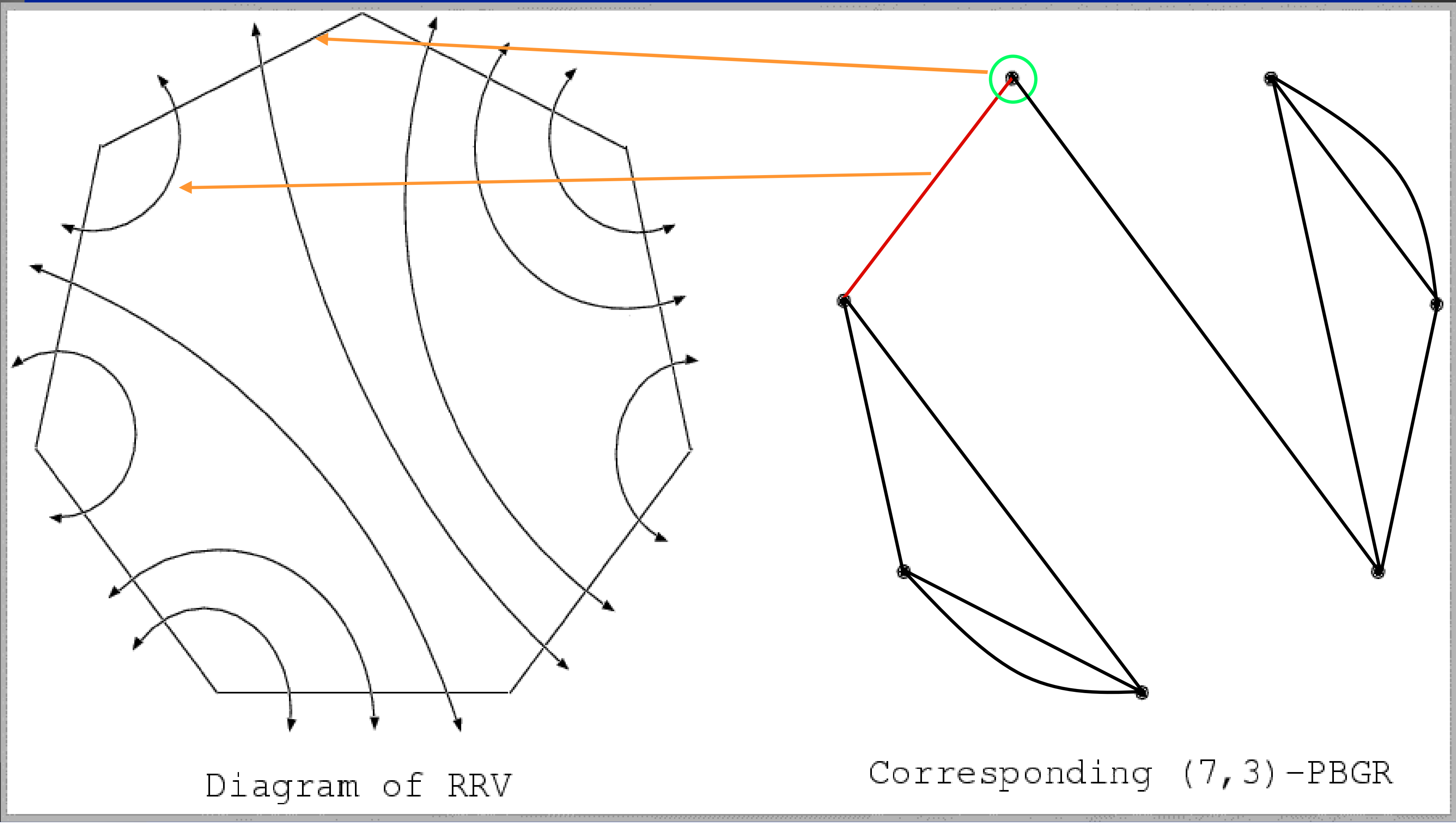
A Counter example of the Generic Universal Switch Blocks

- **A (7,3)-SB $M_{7,3}$ can be decomposed into a (7,2)-SB $M_{7,2}$ and a (7,1)-SB $M_{7,1}$.**



$M_{7,3}$ and its decomposition

- The routing requirement vector (RRV) of $M_{7,3}$ cannot be decomposed into two RRVs that are routable in $M_{7,1}$ and $M_{7,2}$.



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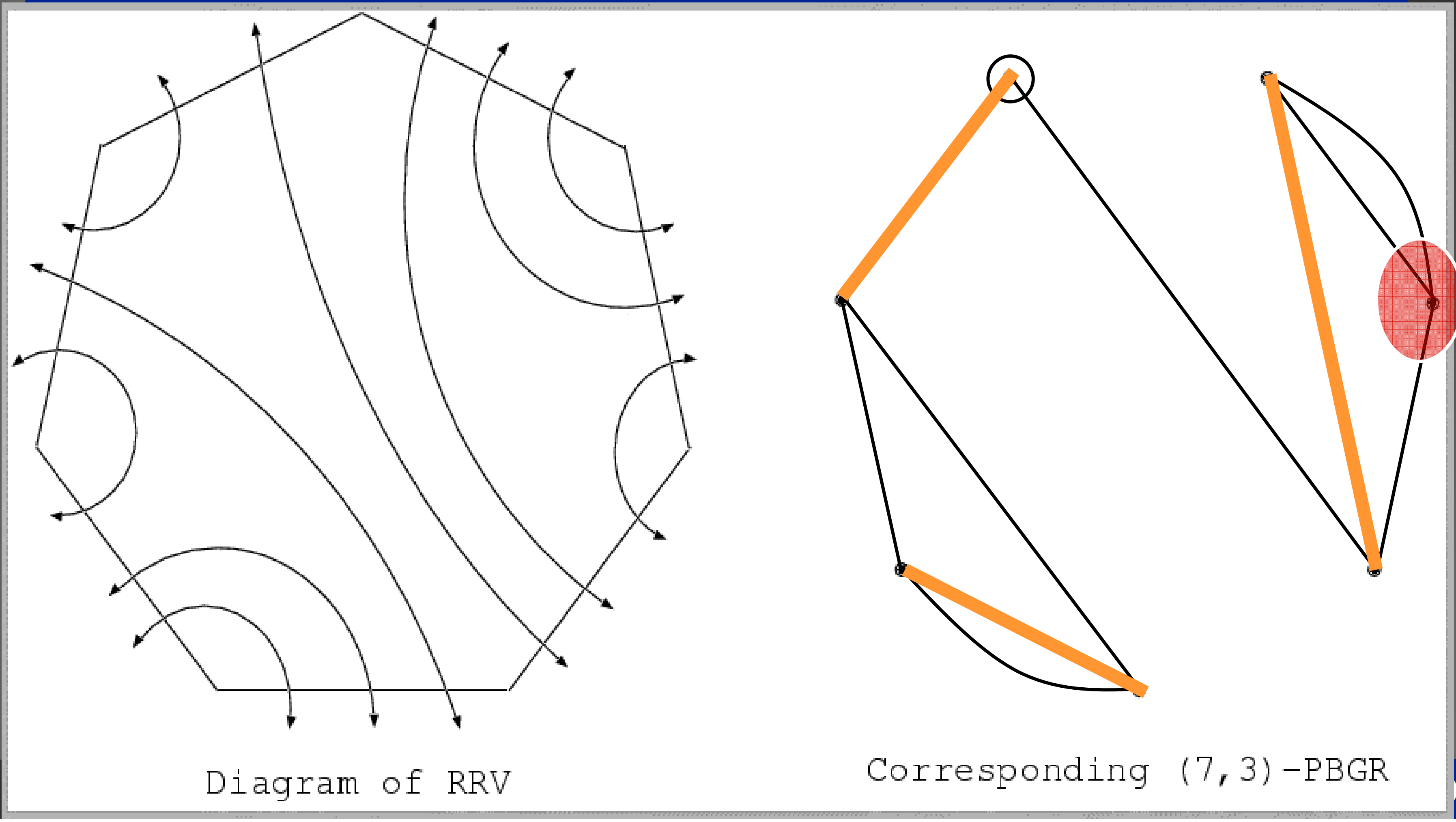

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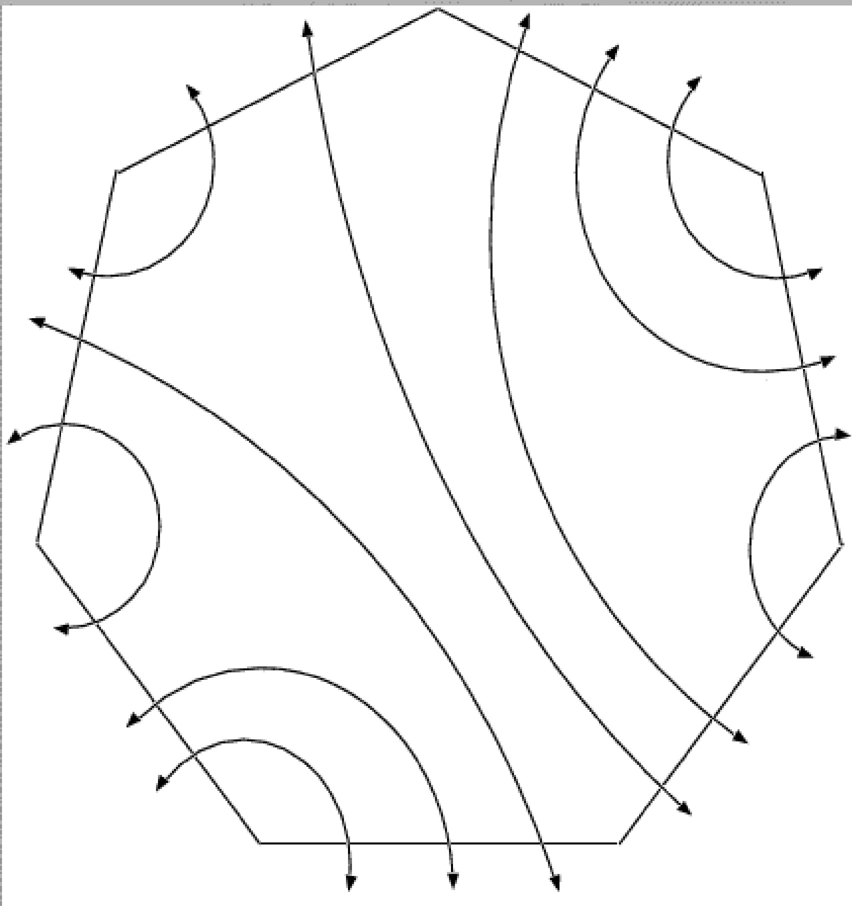
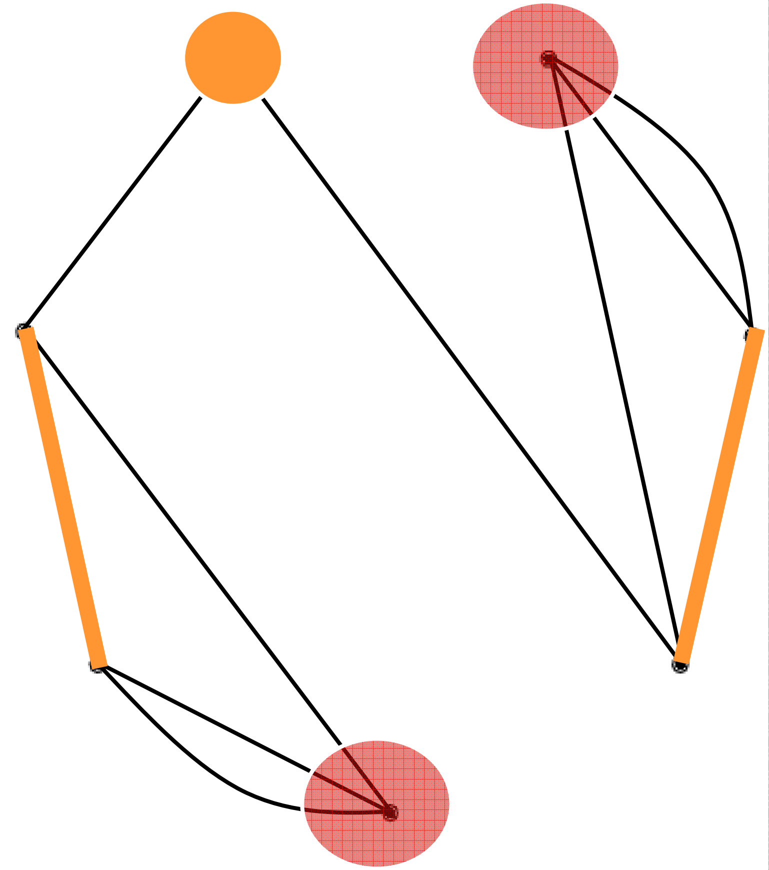


Diagram of RRV



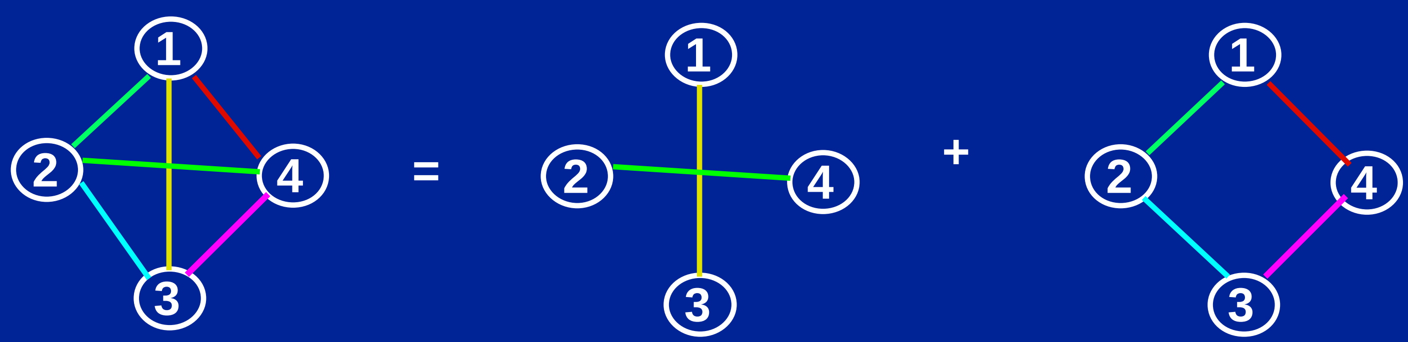
Corresponding (7,3)-PBGR

Universal (k, W)-Design Problem:

- An k-sided switch block with W terminals on each side (k,W)-SB is said to be Universal
  - if every set of (2-pin) nets satisfying the dimension constraint is simultaneously routable on the switch block.
- For even W,
  - A (k,2m)-RR can be decomposed into m (k,2)-RRs
  - A union of m (k,2)-USBs forms a (k,2m)-USB
- For odd W,
  - There is a minimum integer $f_2(k)$ such that a (k,W)-RR can be decomposed into a (k, $f_2(k)$)-RR and some (k,2)-RRs.
  - The problem is: What is the value of $f_2(k)$?

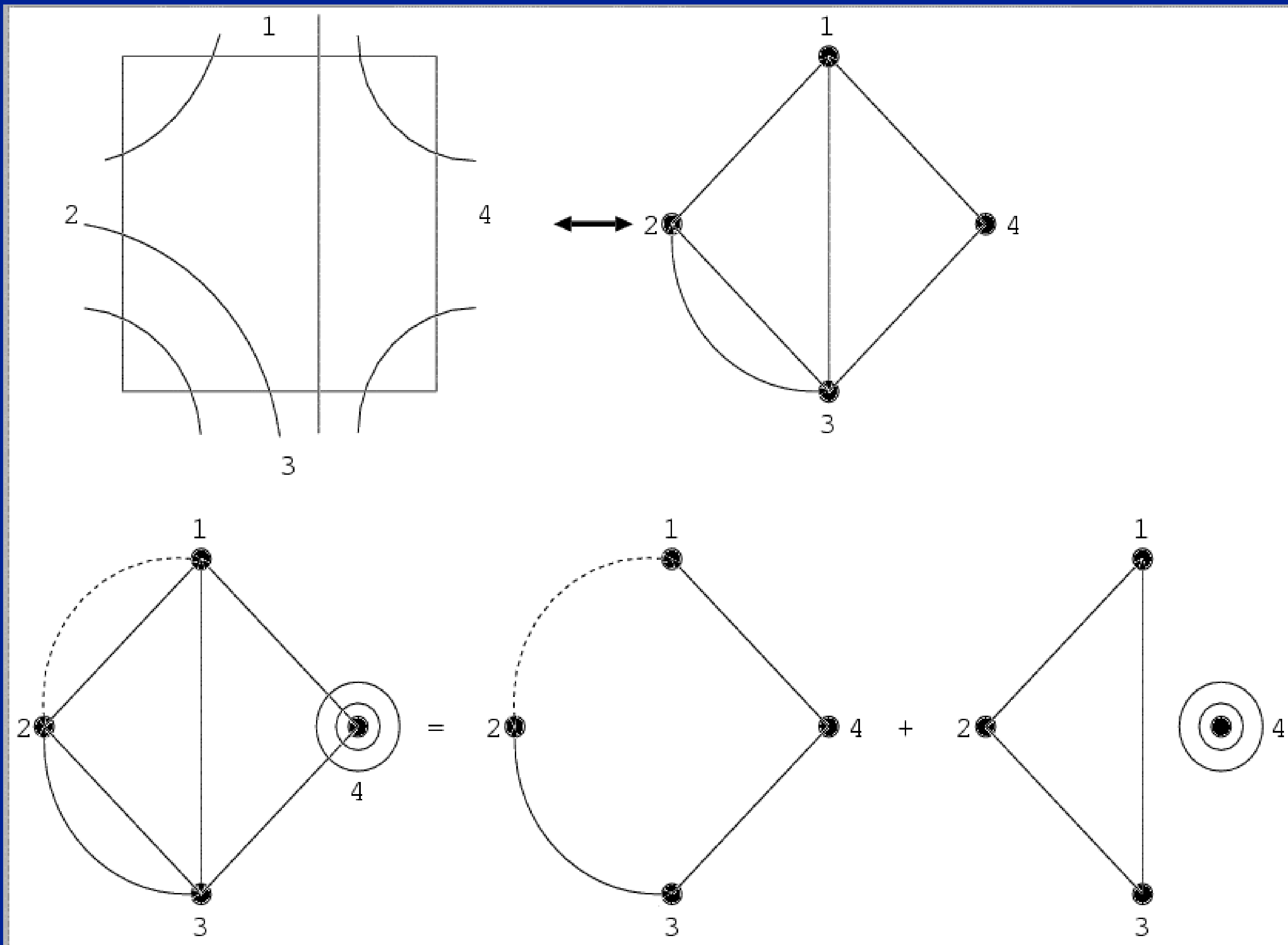
Decomposition Theorem

- Minimal BGR (MBGR) : non decomposable 4-way BGR (regular graph with four nodes)
  - For a fixed *k*, there are finite number of k-MBGRs.
  - Every BGR can be decomposed into the union of MBGRs.
- *f(k)* = maximum density of all k-MBGRs.
  - f(4) = 2
  - all 4-way MBGRs are obtained



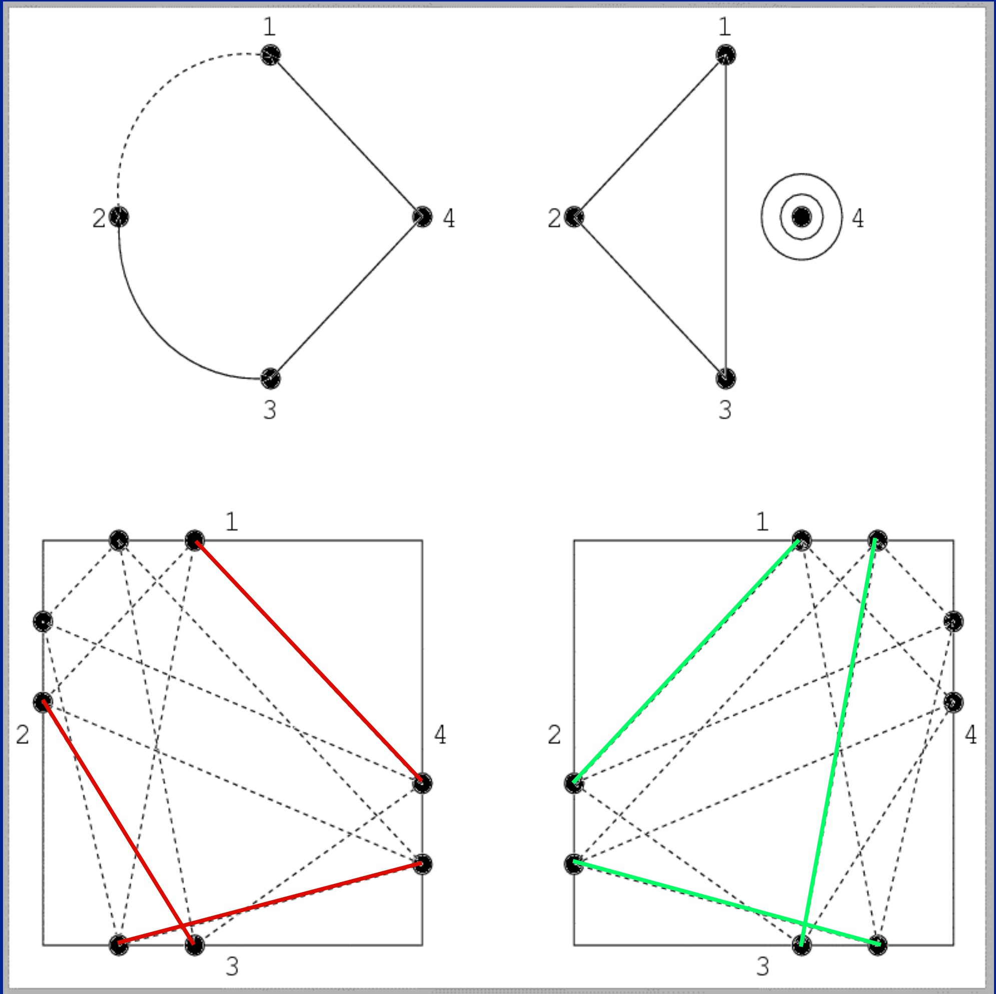
Decomposition of a (4,4)-USB

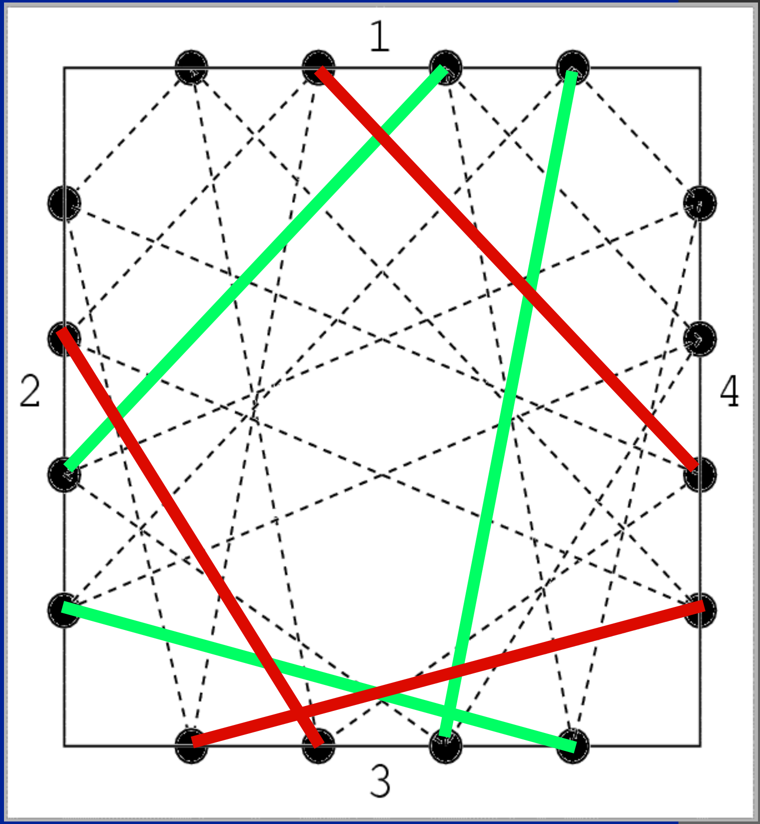
- From RRV to PMBGRs.



A detailed routing example

- The (4,4)-USB is constructed by 2 (4,2)-USBs.





The Extreme Decomposition Theorem

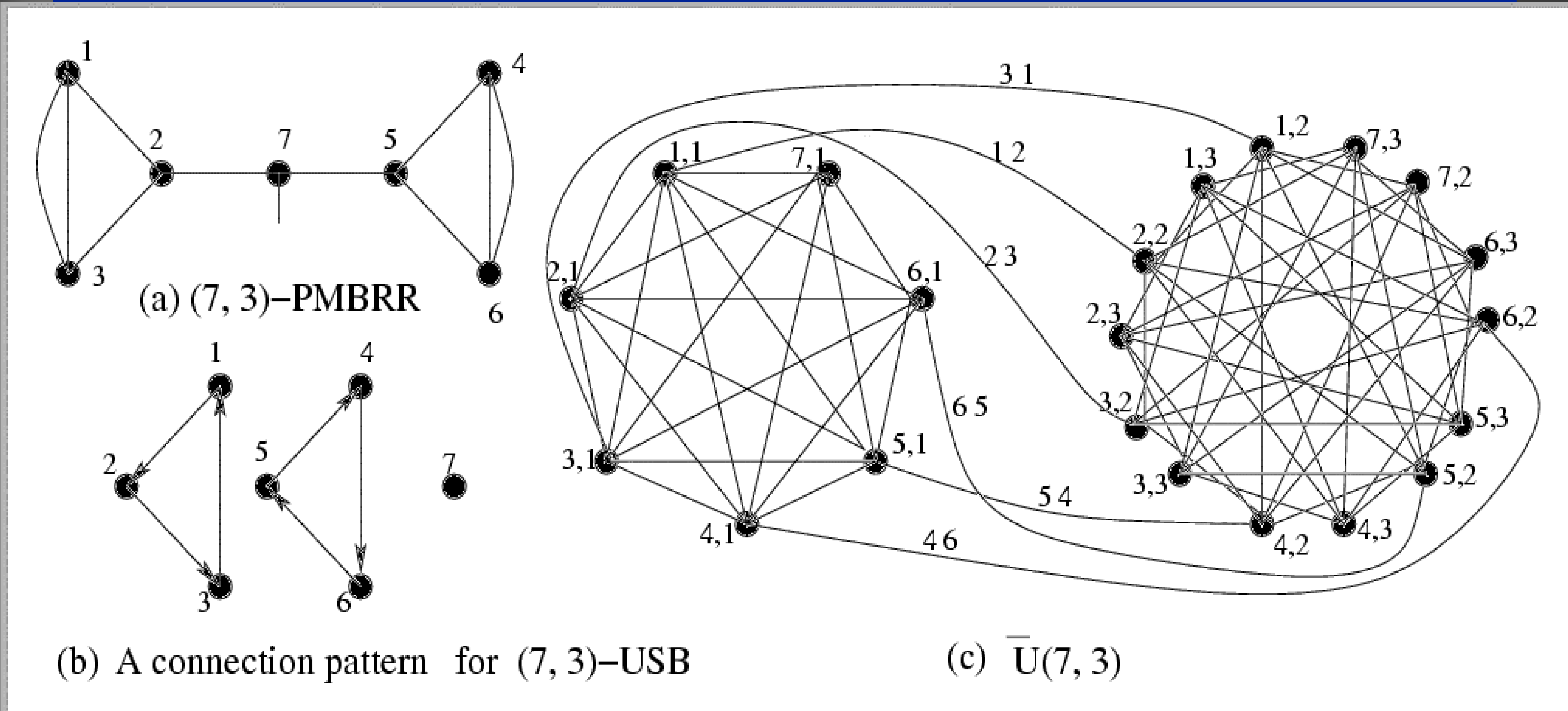
- Every (k,W)-PBRR can be decomposed into k-PMBRRs with densities at most $f_2(k)$
  - $f_2(k) = 1$ for $k = 1,2$
  - $f_2(k) = 2$ for $3 \le k \le 6$
  - $f_2(k) = 3$ for $k = 7, 8$
  - $f_2(k) = (k+3-i) / 3$, where $1 \le i \le 6$, $k = i \pmod 6$
- Every (k,W)-PBRR can be decomposed into a (k,(k+3-i)/3)-PBRR and (3W-k-3+i)/6 (k,2)-PBRRs
- Design basic (k,r)-USBs for r = 1,2,3,5,…, (k+3-i)/3
- (k,2m)-USB is constructed by m (k,2)-USBs
- (k,2m+1)-USB is constructed by one (k, (k+3-i)/3)-USB and (6m-k+i)/6 (k,2)-USBs

Design scheme for Basic (k, W)-USBs

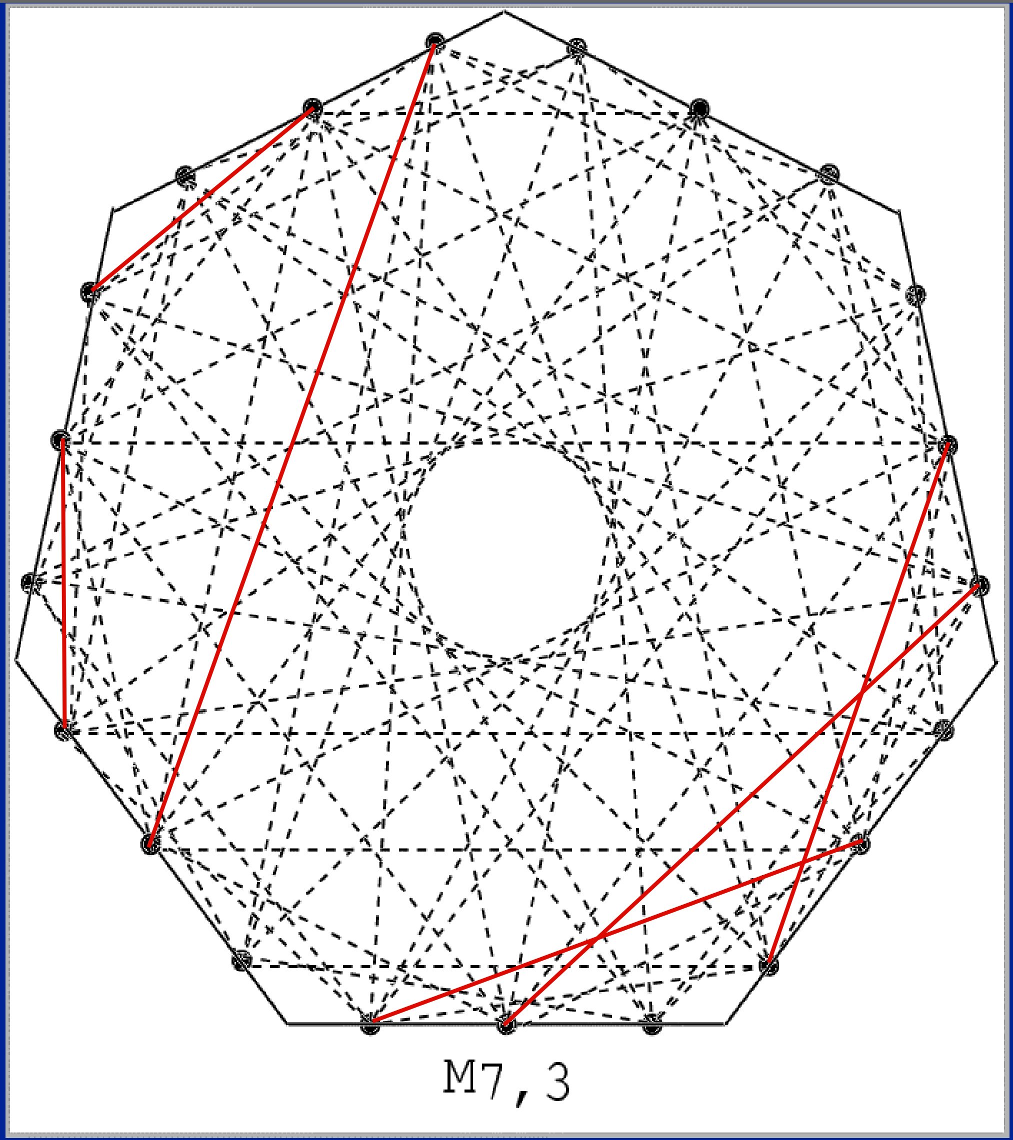
1. The USB design problem is reduced to the design of the basic (k,r)-USBs for r = 1,2,3,5,…,(k+3-i)/3
2. The construction of a (k,3)-USB:
   1. Make a copy of the optimum (k,1)-USB
   2. Make a copy of the optimum (k,2)-USB
   3. Add some switches between them
   4. Verify the resulting SB is routable for all (k,3)-PMBRRs
3. The construction of a (k,5)-USB:
   1. Combine the (k,3)-USB and (k,2)-USB
   2. Add some switches (routable for all (k,5)-PMBRRs
4. Continue until a (k,(k+3-i)/3)-USB is constructed

Example: a (7,3)-USB

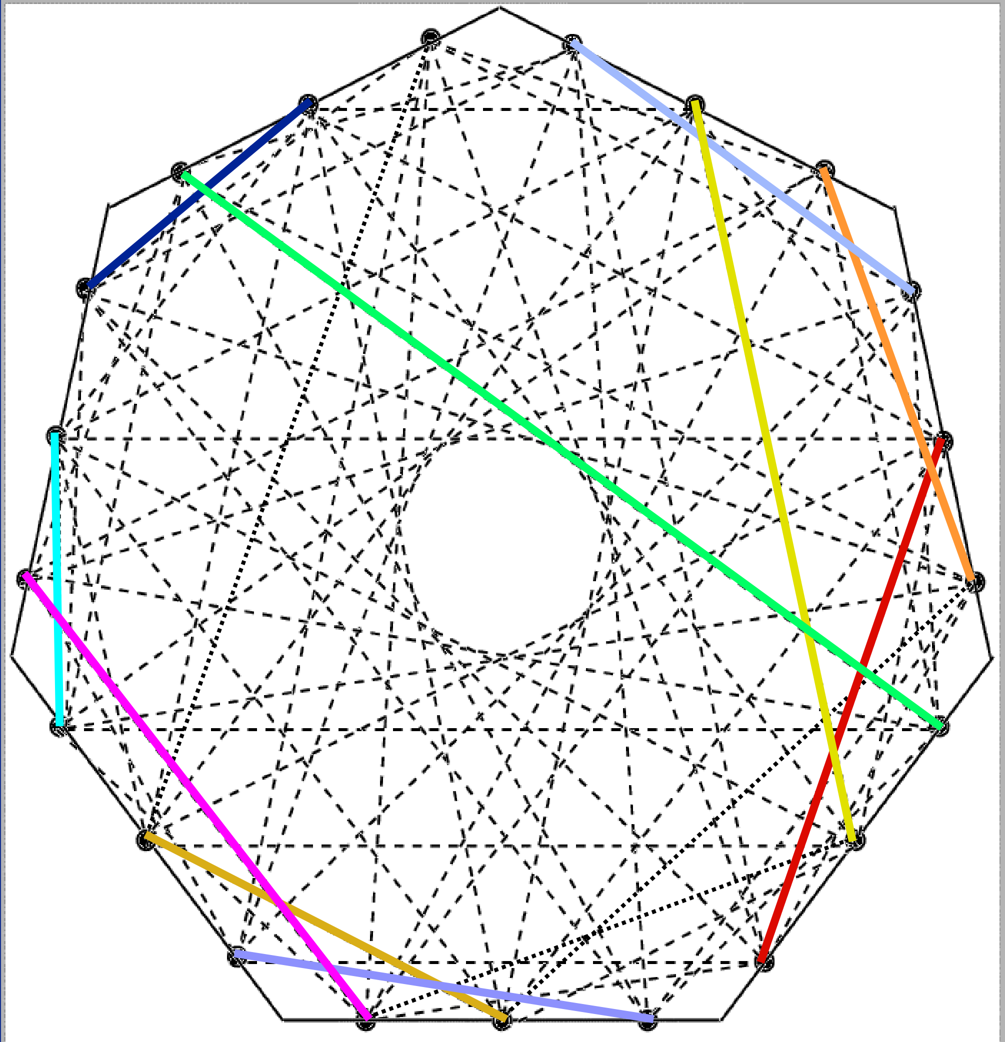
- (7,3)-USB can be constructed by (7,1)-USB + (7,2)-USB, and add some switches (not unique) to ensure the USB is routable for all (7,3)-PMBRRs.

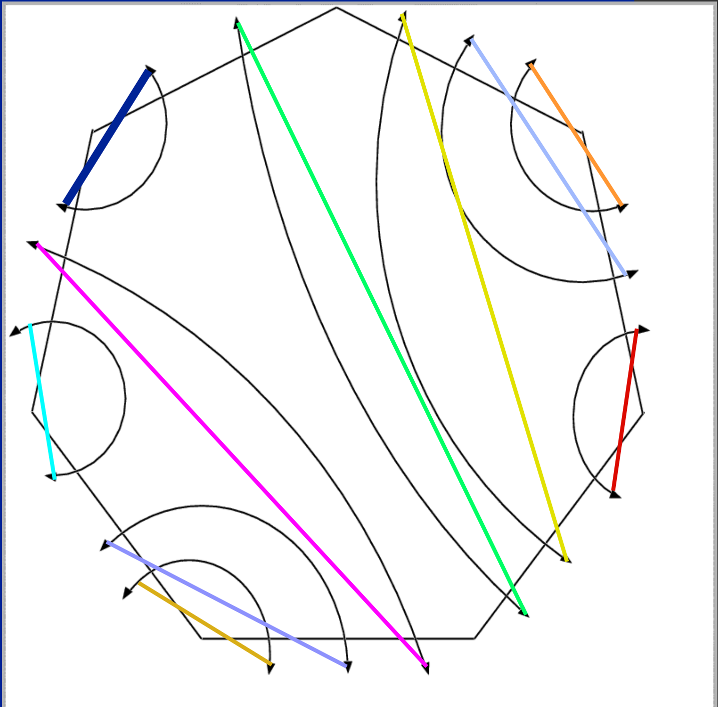


A (7,3)-USB



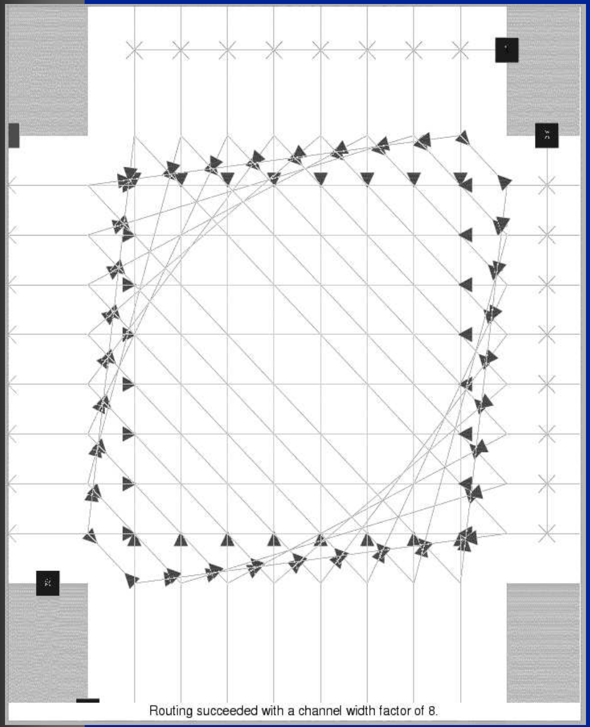
The previous unsolved problem



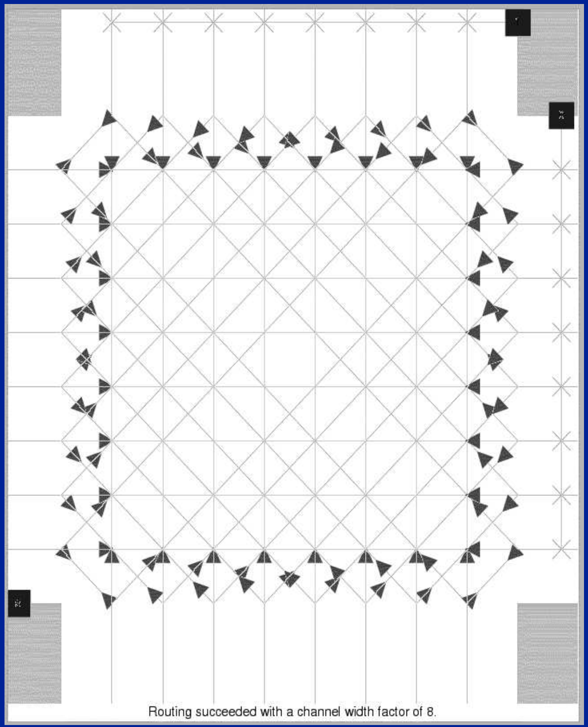


Experiment with USBs

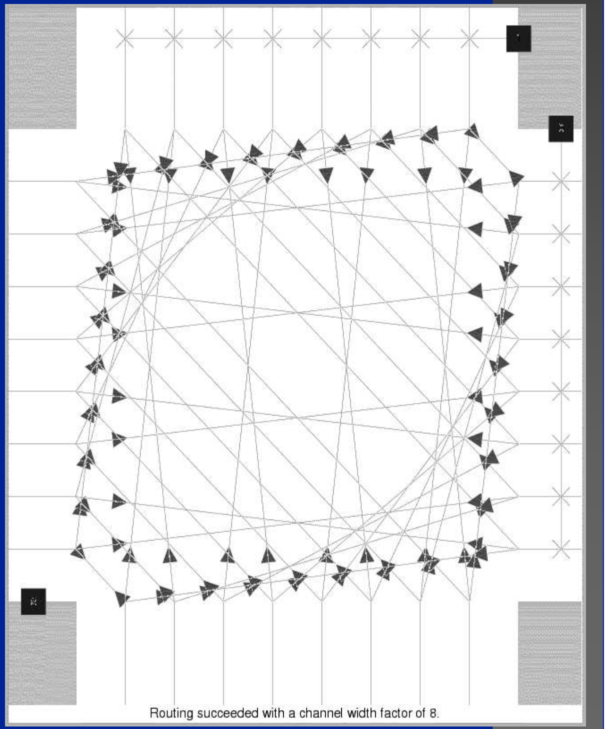
- Run "VPR" on FPGAs with the proposed alternative USBs
  - use 21 MCNC benchmark circuits
- Compare the number of tracks required to route the circuits on FPGAs with disjoint S-Box (XC4000 type) and Symmetric USB designs



Disjoint (4, 8)-SB

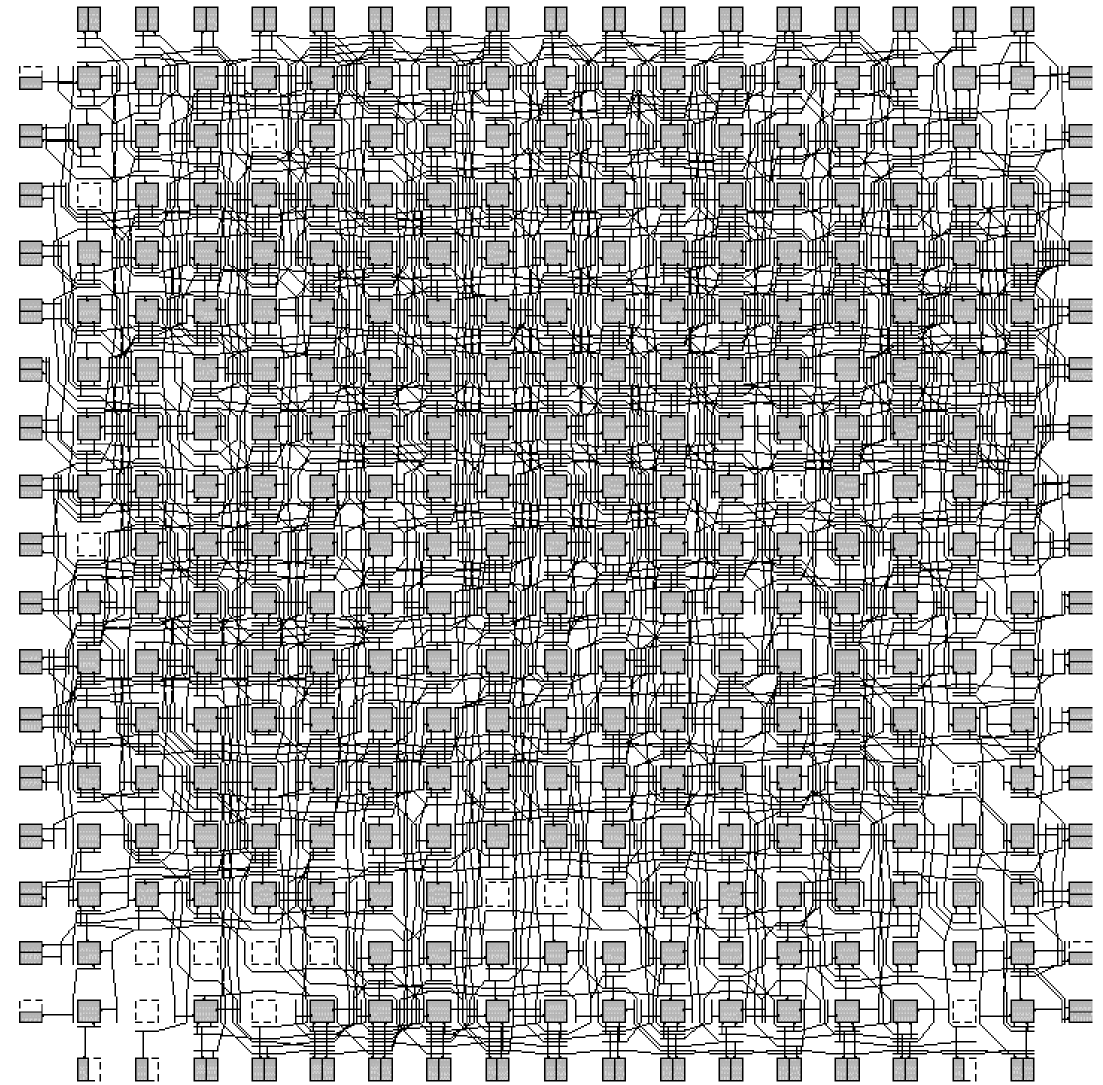


Symmetric (4, 8)-USB



Alternative (4, 8)-USB

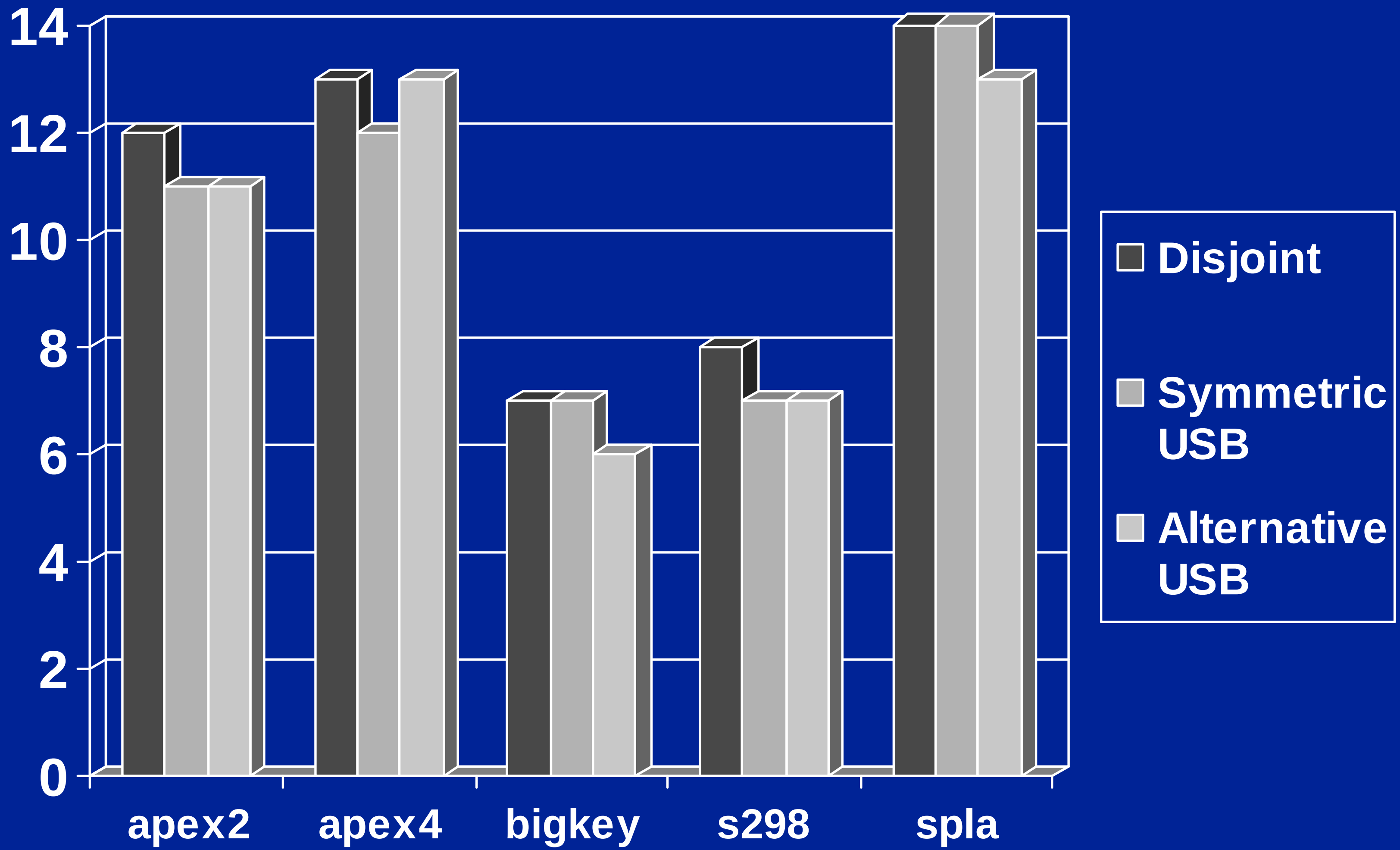
Experiment with USBs – e64



Routing succeeded with a channel width factor of 8.

Experimental Results

- Our USB FPGAs use about 6% less tracks than Disjoint S-box.



Experimental Results

	Disjoint (Subset)	Symmetric USB	Alternative USB
alu4	10	10	10
apex2	12	11	11
apex4	13	12	13
bigkey	7	7	6
clma	13	11	12
des	8	7	7
diffeq	8	7	7
dsip	7	7	7
elliptic	11	10	10
ex1010	11	10	10
…	…	…	…
Total	220	205 (-6.8%)	206 (-6.3%)

Channel densities required for different benchmark circuits

Fc = W, Fs = 3

Conclusions

1. The Optimum USB design problem is solved for odd and even channel densities.
2. The extreme decomposition theorem has reduced the USB design problem to the basic USB design problem.
3. The inductive design scheme is used for designing basic USBs.
4. Experiments show the local optimized USB can bring the improvement of global routability.

The End

- **Please feel free to ask any question !**

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