Techniques for Assigning Inter-Tier Signals to Bondpoints in a Face-to-Face Bonded 3DIC

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Introduction

- In a three-dimensional integrated circuit (3DIC), multiple active layers are stacked vertically to make a single chip
- Why 3DIC? High device density, smaller chip footprint, shorter interconnects, heterogeneous integration, chip security, etc.
- Tiers are interconnected using 3D-vias: top metal layer micro-bumps (bondpoints) or through-silicon-vias (TSVs)
- In a 3DIC, the locations of 3D-vias have a significant effect on cell placement in a tier
- For large designs manual assignment for 3D-vias is impractical and demands automated techniques
- Related work presented an automated approach which uses information only from one tier to make the assignment, while others used a manual assignment
- As face-to-face (F2F) bonded 3DIC is best suited for logic-on-logic stacked 3DIC, four new approaches for assigning signals to bondpoints for this case are introduced
- Proposed techniques successfully automate the assignment and in most cases achieve better results than an architecture-driven manual assignment

Proposed Assignment Techniques

- All techniques are two-step procedures:

1. Estimate the locations of inter-tier signals' source/sink cells
   - Common first step in all techniques
2. Using available bondpoints locations and result of step-1, make an assignment
   - Available bondpoints exclude those reserved for power rails: VDD and Ground
   - Four different procedures are introduced: three variants of nearest-neighbor and one midpoint approach

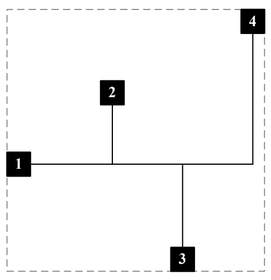
- Using the assignment, a final PAR is executed on both tiers

Inter-Tier Signal Reference Location Estimation

- Procedure:

1. Set inter-tier signals to wires in synthesized netlist
2. Trial place a tier
   - I/O signals and floorplan (if any) guide the trial placement
3. Find the locations of cells that source/sink an inter-tier signal
   - Center of the cell is approximated as the required location

- Fan-out issue: How to choose a location?
  - Random: may not have significant effect
  - Any point on minimum rectilinear Steiner tree
  - Center of the smallest rectangle enclosing sinks
- Past research did not address this issue



Nearest-Neighbor Approach

- In nearest-neighbor (NN), an inter-tier signal is assigned to an available bondpoint which is closest to its reference location

Three types:

- NN1: Reference locations are from tier-1
- NN2: Reference locations are from tier-2
- NNC (Combined): Only location information from source cells is used for assignment
  - Every inter-tier signal has exactly one source cell, and it could be in either one of the tiers
  - For each inter-tier signal, its source cell location is taken from the tier in which it is placed
  - No confusion of which sink cell to select, if fan-out is more than one

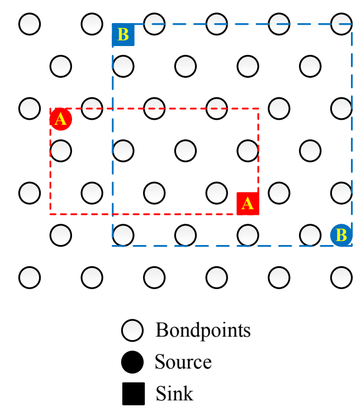
Nearest-Neighbor Algorithm

Input: B – List of M available bondpoint locations
Input: C – List of N source/sink cells locations
Output: A – Assignment List
Require: $N \leq M$

1. **for** each location i in C **do**
2. j = FindClosestBondpoint(i,B);
3. Mark j in B as assigned;
4. Append (i,j) assignment to A;
5. **end for**
6. **return** A;

Midpoint Approach

- Aims to assign a bondpoint that is midway between the source cell in one tier and sink cell in the other tier, along a minimum-distance path
- Source-sink pairs of all inter-tier signals are sorted in increasing order of distance between the source and sink cells and then assigned a bondpoint in that order
  - The closer the pair, the lower the number of candidate bondpoints



Midpoint Algorithm

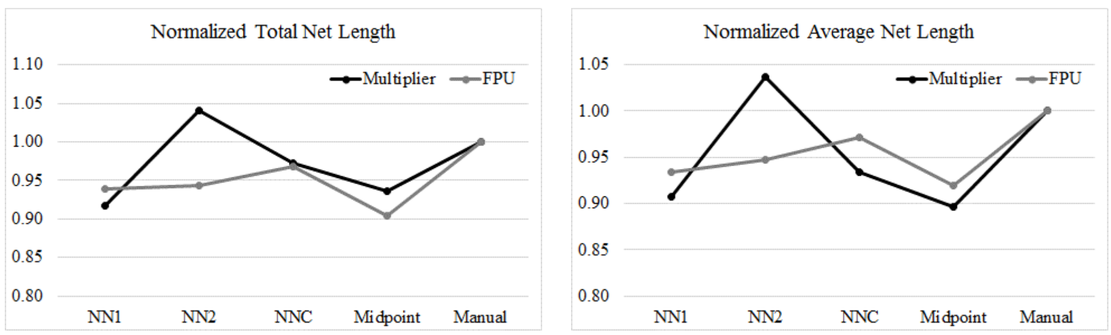
Input: B – List of M available bondpoint locations
Input: CM – List of N entries, each entry a pair of source and sink cells locations, one of them from tier-1 and other from tier-2
Output: A – Assignment List
Require: $N \leq M$

1. **for** each i in CM **do**
2. Compute Manhattan distance between source and sink
3. **end for**
4. $CM \leftarrow$ SortIncreasingOrderOfDistance(CM);
5. **for** each i in CM **do**
6. j = FindMinimumLengthConnectingBondpoint (i,B);
7. Mark j in B as assigned;
8. Append (i,j) assignment to A;
9. **end for**
10. **return** A;

Analysis

- In NNC and midpoint approaches, a temporary placement is required on both the tiers, whereas NN1 and NN2 require a placement in only one of the tiers, tier-1 and tier-2, respectively
- Midpoint is computationally more expensive
  - But all procedures have complexity of $O(M^2)$ in second step
- The order of assignment is fixed in midpoint approach due to sorting, but in NN the order is random

Results and Conclusions



- 3DIC designs of a multiplier and a FPU were implemented with the four proposed techniques, and a manual assignment
- Midpoint results are more consistent than the others, having about 10% lower average net length than manual assignment
- Proposed techniques successfully automate the assignment and in most cases achieve better results than manual method