Chapter IX
Scope for Future Research

The work present in this study may be extended in future on the following lines:

- The work can be carried out on System Level Partitioning and Board level partitioning i.e. the designer must solve two problems: select a set of system components (allocation), partition the system’s functionality among these components (partitioning). The final implementation has to satisfy a set of design constraints, such as cost, performance and power consumption.

- The sample of problem under consideration is taken only using small VLSI Benchmark Circuits. The work can be extended for large IBM circuits.

- The research work is confined to Circuit bi-partitioning. The proposed approaches can be further implemented for multiway circuit partitioning by recursively applying these approaches.

- The research can be further extended to solve min cut partitioning based standard cell global placement by the application of the five developed algorithmic approaches.
Acknowledgments

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Bibliography


Brglez, F.(1998), Design of Experiments to Evaluate CAD Algorithms: Which Improvements Are Due to Improved Heuristic and Which are Merely Due to Chance? A technical report CBL-04-Brglez, *NCSU Collaborative Benchmarking Laboratory*, Raleigh, NC, USA.


Annexure I

Explanation of HABCSACP (Hybrid Artificial Bee Colony Optimization with Simulated Annealing for Circuit Partitioning) Approach

Initial Parameters Settings:

Number of cycles=4  Limit value=2  Number of runs=1  Colony size=5

Step 1: Initialize \((pop\_size,lchrom)\):

Read the input files

The netlist information is stored in .nodes and .nets files.

Convert the .net and .nodes files into netlist format.

A multiword mask of the size of the solution is precomputed for every net by converting the .net and .nodes files into connectivity matrix as shown below.

The connectivity matrix of spp_N10_E7_R1_1025 circuit

<table>
<thead>
<tr>
<th></th>
<th>a0</th>
<th>a1</th>
<th>a2</th>
<th>a3</th>
<th>a4</th>
<th>a5</th>
<th>a6</th>
<th>a7</th>
<th>a8</th>
<th>a9</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Netlist preprocessing

Single pin nets are removed from the netlist. Single pin nets may result from unconnected pins on standard cells which are assigned dummy net names. The netlist is mapped to another netlist on which the proposed algorithm is run.

The connectivity matrix of spp_N10_E7_R1_1025 circuit after removal of single pin net

<table>
<thead>
<tr>
<th></th>
<th>a0</th>
<th>a1</th>
<th>a2</th>
<th>a3</th>
<th>a4</th>
<th>a5</th>
<th>a6</th>
<th>a7</th>
<th>a8</th>
<th>a9</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>
Randomly generate an initial colony $P$ of size $\text{colony\_size}$

Taking $\text{colony\_size}=5$ randomly generate 5 solutions with 10 vertices

Encoding the population as bit strings

Encode every random solution of the population as $<0,1>$ tuple of size equal to number of vertices, assigning bits in such a manner that the encoded random solutions are feasible solutions (i.e. balanced partition w.r.t weight of vertices).

Read the weight of every cell of circuit from the file $\text{spp\_N10\_E7\_R1\_1025.wts}$.

The cell weights nodes of $\text{spp\_N10\_E7\_R1\_1025}$ circuit

<table>
<thead>
<tr>
<th>cell #.</th>
<th>a0</th>
<th>a1</th>
<th>a2</th>
<th>a3</th>
<th>a4</th>
<th>a5</th>
<th>a6</th>
<th>a7</th>
<th>a8</th>
<th>a9</th>
<th>size</th>
</tr>
</thead>
<tbody>
<tr>
<td>cell</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>2904000</td>
</tr>
<tr>
<td>size</td>
<td></td>
<td>1307000</td>
<td>1307000</td>
<td>1307000</td>
<td>1307000</td>
<td>2904000</td>
<td>2904000</td>
<td>2904000</td>
<td>2904000</td>
<td>3630000</td>
<td></td>
</tr>
</tbody>
</table>

Calculate the net cut of each solution in the population using the net cut evaluation mechanism.

<table>
<thead>
<tr>
<th>Net cut evaluation of 5 random solutions</th>
<th>Netcut</th>
<th>Trial</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 1 0 1 0 1 0 1 1 0</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>1 0 1 1 0 0 1 0 0 0</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>1 1 0 0 1 0 0 1 1 0</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>1 1 0 1 0 0 0 1 1 0</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>1 0 1 1 0 1 0 1 1 0</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>

OUTPUT (1 RUN)

**Cycle 1**

Solution 1

| 1 1 0 1 0 1 0 1 1 0 | Netcut=3 |

Randomly selected swap points say 5 and 9

The new solution after swap

| 1 1 0 1 1 1 0 1 0 0 | Netcut=3 |

As the new solution do not give better net cut so retain the original solution. Because the original solution has not been modified so increase the trial value associated with solution 1. Trial=trial+1. Therefore trial value of solution 1 becomes 1.
Solution 2

\begin{verbatim}
1 0 1 1 0 0 1 0 0 0 Netcut=3
\end{verbatim}

Randomly selected swap points say 2 and 3

The new solution after swap

\begin{verbatim}
1 1 0 1 0 0 1 0 0 0 Netcut=5
\end{verbatim}

As the new solution do not give better net cut so retain the original solution. Because the original solution has not been modified so increase the trial value associated with solution 2. Trial=trial+1. Therefore trial value of solution 2 becomes 1.

Solution 3

\begin{verbatim}
1 1 0 0 1 0 0 1 1 0 Netcut=4
\end{verbatim}

Randomly selected swap points say 6 and 1

The new solution after swap

\begin{verbatim}
1 0 0 0 1 0 0 0 0 0 Netcut=3
\end{verbatim}

As the new solution has better net cut so replace the original solution with the new solution. Because the original solution has been modified so set trial value associated with solution 3 as 0.

Solution 4

\begin{verbatim}
1 1 0 1 0 0 0 1 1 0 Netcut=4
\end{verbatim}

Randomly selected swap points say 5 and 3

The new solution after swap

\begin{verbatim}
1 1 0 1 0 0 0 1 1 0 Netcut=4
\end{verbatim}

As the new solution do not give better net cut so retain the original solution. Because the original solution has not been modified so increase the trial value associated with solution 4. Trial=trial+1. Therefore trial value of solution 4 becomes 1.

Solution 5

\begin{verbatim}
1 0 1 1 0 1 0 1 1 0 Netcut=5
\end{verbatim}

Randomly selected swap points say 9 and 7

The new solution after swap

\begin{verbatim}
1 0 1 1 0 1 1 1 0 0 Netcut=3
\end{verbatim}

As the new solution has better net cut so replace the original solution with the new solution. Because the original solution has been modified so set trial value associated with solution 5 as 0.

Output after send employed bees

\begin{verbatim}
<table>
<thead>
<tr>
<th>Solution</th>
<th>Netcut</th>
<th>Trial</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 1 0 1 0 1 0 1 1 0</td>
<td>Netcut=3</td>
<td>Trial=1</td>
</tr>
<tr>
<td>1 0 1 1 0 0 1 0 0 0</td>
<td>Netcut=3</td>
<td>Trial=1</td>
</tr>
<tr>
<td>1 0 0 0 1 0 0 0 0 0</td>
<td>Netcut=3</td>
<td>Trial=0</td>
</tr>
<tr>
<td>1 1 0 1 0 0 1 1 1 0</td>
<td>Netcut=4</td>
<td>Trial=1</td>
</tr>
<tr>
<td>1 0 1 1 0 1 1 1 0 0</td>
<td>Netcut=3</td>
<td>Trial=0</td>
</tr>
</tbody>
</table>
\end{verbatim}
Probability calculation ( ) : Output after probability calculation

<table>
<thead>
<tr>
<th></th>
<th>Netcut</th>
<th>Fitness</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 1 0 1 0 1 0 1 0 1</td>
<td>3</td>
<td>2.500000e-001</td>
<td>2.083333e-001</td>
</tr>
<tr>
<td>1 0 1 0 0 1 0 0 0 0</td>
<td>3</td>
<td>2.500000e-001</td>
<td>2.083333e-001</td>
</tr>
<tr>
<td>1 0 0 0 1 0 0 0 0 0</td>
<td>3</td>
<td>2.500000e-001</td>
<td>2.083333e-001</td>
</tr>
<tr>
<td>1 1 0 1 0 0 0 1 0 0</td>
<td>4</td>
<td>2.000000e-001</td>
<td>1.666667e-001</td>
</tr>
<tr>
<td>1 0 1 0 0 1 1 0 0 0</td>
<td>3</td>
<td>2.500000e-001</td>
<td>2.083333e-001</td>
</tr>
</tbody>
</table>

Send onlookerbess ( )

Solution 1
1 0 1 0 1 0 1 1 0 1
Netcut=3
Fitness=2.500000e-001
Prob.=2.083333e-001

Randomly generated value for send onlooker bees to swap the solution 0.395109
Random value 3.951086e-001 > probability of solution 2.083333e-001, therefore no change

Solution 2
1 0 1 1 0 0 1 0 0 0
Netcut=3
Fitness=2.500000e-001
Prob.=2.083333e-001

Randomly generated value for send onlooker bees to swap the solution 0.113304
Random value 1.133042e-001 < probability of solution 2.083333e-001
1 0 1 1 0 0 1 0 0 0
Solution after swap with random points 10 and 5
1 0 1 1 0 0 0 0 1 0
Netcut=3
Therefore no change in solution

Solution 3
1 0 0 0 0 1 0 0 0 0
Netcut=3
Fitness=2.500000e-001
Prob.=2.083333e-001

Randomly generated value for send onlooker bees to swap the solution 0.263896
Random value 2.638965e-001 > probability of solution 2.083333e-001, therefore no change

Solution 4
1 1 0 1 0 0 0 1 1 0
Netcut=4
Fitness=2.000000e-001
Prob.=1.666667e-001

Randomly generated value for send onlooker bees to swap the solution 0.342483
Random value 3.424827e-001 > probability of solution 1.666667e-001, therefore no change

Solution 5
1 0 1 1 0 1 1 1 0 0
Netcut=3
Fitness=2.500000e-001
Prob.=2.083333e-001

Randomly generated value for send onlooker bees to swap the solution 0.145697
Random value 1.456968e-001 < probability of solution 2.083333e-001
1 0 1 1 0 1 1 0 0 0
Solution after swap with random points 9 and 2

\[
\begin{array}{cccccccccc}
1 & 0 & 1 & 1 & 1 & 0 & 1 & 1 & 0 & 0 \\
\end{array}
\]

net cut = 3

Therefore no change in solution

**Output of Send onlooker bees**

<table>
<thead>
<tr>
<th>Solution</th>
<th>Netcut</th>
<th>Fitness</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 1 0 1 0 1 1 0</td>
<td>3</td>
<td>2.500000e-001</td>
<td>2.083333e-001</td>
</tr>
<tr>
<td>1 0 1 0 0 1 0 0 0</td>
<td>3</td>
<td>2.500000e-001</td>
<td>2.083333e-001</td>
</tr>
<tr>
<td>1 0 0 1 0 0 0 0 0</td>
<td>3</td>
<td>2.500000e-001</td>
<td>2.083333e-001</td>
</tr>
<tr>
<td>1 1 0 1 0 0 1 1 0</td>
<td>4</td>
<td>2.000000e-001</td>
<td>1.666667e-001</td>
</tr>
<tr>
<td>1 0 1 1 0 1 1 0 0</td>
<td>3</td>
<td>2.500000e-001</td>
<td>2.083333e-001</td>
</tr>
</tbody>
</table>

MemorizeBestSource ( )

\[
\begin{array}{cccccccccc}
1 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 1 & 0 \\
\end{array}
\]

Netcut = 3

SendScoutBees ( )

Because the trail of the solution 2 (trial value=2) is greater than limit so discard this solution and replace it with new generated solution with trial value=0.

Discarded solution

\[
\begin{array}{cccccccccc}
1 & 0 & 1 & 1 & 0 & 0 & 1 & 0 & 0 & 0 \\
\end{array}
\]

Replaced solution

\[
\begin{array}{cccccccccc}
1 & 1 & 1 & 1 & 1 & 1 & 0 & 1 & 1 & 0 \\
\end{array}
\]

**Output of SendScoutBees**

<table>
<thead>
<tr>
<th>Solution</th>
<th>Netcut</th>
<th>Trial</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 1 0 1 0 1</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>1 1 1 1 1</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>1 0 0 1 0 0</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>1 1 0 1</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>1 0 1 1</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

**Cycle 2**

Solution 1

\[
\begin{array}{cccccccccc}
1 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 1 & 0 \\
\end{array}
\]

Randomly selected swap points say 6 and 7

The new solution after swap

\[
\begin{array}{cccccccccc}
1 & 1 & 0 & 1 & 0 & 0 & 1 & 1 & 1 & 0 \\
\end{array}
\]

Netcut = 5

As the new solution do not give better net cut so retain the original solution. Because the original solution has not been modified so increase the trial value associated with solution 1. Trial=trial+1. Therefore trial value of solution 1 becomes 1.

Solution 2

\[
\begin{array}{cccccccccc}
1 & 1 & 1 & 1 & 1 & 1 & 0 & 1 & 1 & 0 \\
\end{array}
\]

Randomly selected swap points say 1 and 4

The new solution after swap
As the new solution do not give better net cut so retain the original solution. Because the original solution has not been modified so increase the trial value associated with solution 2. Trial=trial+1. Therefore trial value of solution 2 becomes 1.

Solution 3
1 0 0 0 1 0 0 0 0 0 0 0 Netcut=3
Randomly selected swap points say 9 and 6
The new solution after swap
1 0 0 0 1 0 0 0 0 0 0 0 Netcut=3
As the new solution do not give better net cut so retain the original solution. Because the original solution has not been modified so increase the trial value associated with solution 3. Trial=trial+1. Therefore trial value of solution 3 becomes 1.

Solution 4
1 1 0 1 0 0 0 1 1 0 0 Netcut=4
Randomly selected swap points say 8 and 1
The new solution after swap
1 0 0 0 1 0 1 1 1 1 0 Netcut=4
As the new solution do not give better net cut so retain the original solution. Because the original solution has not been modified so increase the trial value associated with solution 4. Trial=trial+1. Therefore trial value of solution 4 becomes 2.

Solution 5
1 0 1 1 0 1 1 1 0 0 0 Netcut=3
Randomly selected swap points say 9 and 6
The new solution after swap
1 0 1 1 0 0 1 1 1 1 0 Netcut=3
As the new solution do not give better net cut so retain the original solution. Because the original solution has not been modified so increase the trial value associated with solution 5. Trial=trial+1. Therefore trial value of solution 5 becomes 2.

**Output after send employed bees**

<table>
<thead>
<tr>
<th></th>
<th>Netcut</th>
<th>Trial</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 1 0 1 0 1 1 0 1 1 0 1 0 3 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 1 1 1 1 1 1 0 1 1 0 1 0 3 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 0 0 0 1 0 0 0 0 0 0 0 0 3 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 1 0 1 0 0 0 1 1 1 0 1 0 4 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 0 1 1 0 1 1 1 0 0 0 0 3 2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Probability calculation ( ) : Output after probability calculation**

<table>
<thead>
<tr>
<th></th>
<th>Netcut</th>
<th>Fitness</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 1 0 1 0 1 1 0</td>
<td>Netcut=3</td>
<td>Fitness=2.500000e-001</td>
<td>Prob.=2.083333e-001</td>
</tr>
<tr>
<td>1 1 1 1 1 0 1 1 0</td>
<td>Netcut=3</td>
<td>Fitness=2.500000e-001</td>
<td>Prob.=2.083333e-001</td>
</tr>
<tr>
<td></td>
<td>Netcut</td>
<td>Fitness</td>
<td>Prob.</td>
</tr>
<tr>
<td>---------</td>
<td>--------</td>
<td>----------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>1 0 0 1 0 0 0 0</td>
<td>3</td>
<td>2.500000e-001</td>
<td>2.083333e-001</td>
</tr>
<tr>
<td>1 1 0 1 0 0 1 1 0</td>
<td>4</td>
<td>2.000000e-001</td>
<td>1.666667e-001</td>
</tr>
<tr>
<td>1 0 1 1 0 1 1 0 0</td>
<td>3</td>
<td>2.500000e-001</td>
<td>2.083333e-001</td>
</tr>
</tbody>
</table>

**Send onlooker bees ( )**

**Solution 1**

```
1 1 0 1 0 1 0 1 1 0
```

Netcut=3, Fitness=2.500000e-001, Prob.=2.083333e-001

Randomly generated value for send onlooker bees to swap the solution: 0.322425

Random value 3.224245e-001 > probability of solution 2.083333e-001, therefore no change

**Solution 2**

```
1 1 1 1 1 1 0 1 1 0
```

Netcut=3, Fitness=2.000000e-001, Prob.=1.666667e-001

Randomly generated value for send onlooker bees to swap the solution: 0.039156

Random value 3.915579e-002 < probability of solution 2.083333e-001

```
1 1 1 1 1 1 0 1 1 0
```

Solution after swap with random points 4 and 3

```
1 1 1 1 1 1 0 1 1 0
```

Netcut=3

Therefore no change in solution

**Solution 3**

```
1 0 0 0 1 0 0 0 0 0
```

Netcut=3, Fitness=2.500000e-001, Prob.=2.083333e-001

Randomly generated value for send onlooker bees to swap the solution: 0.184059

Random value 1.840594e-001 < probability of solution 2.083333e-001

```
1 0 0 0 1 0 0 0 0 0
```

Solution after swap with random points 3 and 5

```
1 0 1 0 0 0 0 0 0 0
```

Netcut=3

Therefore no change in solution

**Solution 4**

```
1 1 0 1 0 0 0 1 1 0
```

Netcut=4, Fitness=2.000000e-001, Prob.=1.666667e-001

Randomly generated value for send onlooker bees to swap the solution: 0.142532

Random value 1.425320e-001 < probability of solution 1.666667e-001

```
1 1 0 1 0 0 0 1 1 0
```

Solution after swap with random points 9 and 10

```
1 1 0 1 0 0 0 1 0 1
```

Netcut=3

Replace the old solution with new one.
Solution 5
1 0 1 1 0 1 1 1 0 0 netcut=3
probability=2.083333e-001

Randomly generated value for send onlooker bees to swap the solution 0.397480
Random value 3.974804e-001 > probability of solution 2.083333e-001, therefore no change
Output after Send onlookerbees ()

MemorizeBestsource ()

SendScoutBees ()
Because the trail of the solution 2 (trial value=2) is greater than limit so discard this solution and replace it with new generated solution with trial value=0.
Discarded solution
1 1 1 1 1 0 1 1 0 0
Replaced solution
1 0 1 1 1 0 1 1 0 0
Because the trail of the solution 3 (trial value=2) is greater than limit so discard this solution and replace it with new generated solution with trial value=0.
Discarded solution
1 0 0 0 0 0 1 0 0 0
Replaced solution
1 1 0 0 0 0 1 1 0 0
Because the trail of the solution 5 (trial value=2) is greater than limit so discard this solution and replace it with new generated solution with trial value=0.
Discarded solution
1 1 0 1 0 0 0 0 0 0
Replaced solution
1 1 1 0 1 0 1 1 0 0
Output of SendScoutBees ()

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