Multi-Voltage Floorplan Design with Optimal Voltage Assignment

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Dilemma between delay & power

- Power is proportional to Voltage
- Gate Delay is adversely proportional to Voltage
Problem Formulation

- Given a netlist of modules, each of which has multiple choices of supply voltages and corresponding power consumptions, and a clock cycle, generate a floorplan with a voltage assignment to each module such that the timing constraint is satisfied and a weighted sum of the total power consumption (due to cells and level shifters), power network routing resources, area and wire length is minimized.
Problem Formulation

- **Power-delay trade-off**

  The power-delay trade-off in cell $m_1$ is represented by $k_1$ delay-power pairs, \( \{(d^1_{i_1}, p^1_{i_1}), (d^2_{i_1}, p^2_{i_1}), \ldots, (d^{k_1}_{i_1}, p^{k_1}_{i_1})\} \).
Problem Formulation

Minimize: \( \sum_{v_i \in V} \sum_{q=1}^{k_i} p_i^q u_i(q) + \sum_{(i,j) \in E} LS(i,j) \cdot \varphi \) \hspace{1cm} (1a)

Subject to:

\( \sum_{q=1}^{k_i} u_i(q) = 1 \quad \forall v_i \in V \) \hspace{1cm} (1b)

\( \sum_{e=(i,j) \in E} \left( \sum_{q=1}^{k_i} d_i^q u_i(q) + \rho LS(i,j) + \omega(i,j) \right) \leq T_{cycle} \quad \forall C \in \Phi_k \) \hspace{1cm} (1c)

\( LS(i,j) = \begin{cases} 0 & \sum_{q=1}^{k_i} v_i^q u_i(q) \geq \sum_{q=1}^{k_i} v_j^q u_j(q) \\ 1 & \text{otherwise} \end{cases} \) \hspace{1cm} (1d)

\( u_i(q) \in \{0,1\} \quad q = 1,2,...,k_i, \forall v_i \in V \) \hspace{1cm} (1e)
Problem Formulation

- Modeling used in our approach
  - Directed Graph
  - DP-Curve
Problem Formulation

- Directed Graph

Diagram showing a directed graph with nodes labeled 0, 1, 2, 3, 4, and 5, connected with directed edges.
Problem Formulation

- DP-Curve

![Diagram of DP-Curve with points (d₁, p₁) at v₁, (d₂, p₂) at v₂, and (d₃, p₃) at v₃ on a graph with Power on the y-axis and Delay on the x-axis.](image-url)
Previous Work


Previous Work

Our Approach-Branch and Bound

- NP-hard[3]
- Branch & Bound Search
  - Branching Rules
  - Upper Bounds
  - Lower Bounds
  - Pruning Rules
  - Value-Oriented Searching Rules

Branching Rules

- Original problem
- Sub-problems

Cell 1 works at $v_1^1$

Cell 1 works at $v_1^2$

Cell 1 works at $v_1^{k_1}$

Cell 1 works at $v_1^{k_2}$

Cell 2 works at $v_2^1$

Cell 2 works at $v_2^{k_2}$

Call Ma’s work
Upper Bound

Lower Bound

- Linear Relaxation

Minimize: \( \sum_{v \in V} \sum_{q=1}^{k_1} p_i^q u_l(q) + \sum_{e \in E} LS(i, j) \cdot \varphi \)  \hspace{1cm} (5a)

Subject to:

\( \sum_{q=1}^{k_1} u_l(q) = 1 \quad \forall v \in V \)  \hspace{1cm} (5h)

\( \sum_{e \in E} \left( \sum_{q=1}^{k_1} d_e^q u_l(q) + \rho LS(i, j) + \omega(i, j) \leq T_{cycle} \right) \quad \forall C \in \Phi_k \)  \hspace{1cm} (5c)

\( LS(i, j) \geq u_l(q_1) + u_l(q_2) - 1 \)  \hspace{1cm} (5d)

\( \forall e \in E, \forall q_1, q_2 \text{ s.t. } (0 \leq q_1, q_2 \leq k) \land (q_2 > q_1) \)  \hspace{1cm} (5e)

\( 0 \leq LS(i, j) \leq 1, \forall e \in E \)  \hspace{1cm} (5e)

\( 0 \leq u_l(q) \leq 1, \quad q = 1, 2, ..., k_l, \forall v \in V \)  \hspace{1cm} (5f)
We will prune a subtree when

- The approach in [2] cannot return a feasible supply voltage level satisfying the timing constraint even assuming a continuous domain for the module voltage

- Lower bound is greater than or equal to the global upper bound

Value-Oriented Searching Rules

- Search those sub-trees with a higher chance of returning an optimal solution
- Use a variable called “target” to guide the searching
- Search into a sub-tree of some vertex only when the lower bound of that vertex is less than this target
- Increase the target by a constant after each searching
Value-Oriented Searching Rules

Initially

target = 0.6(low_bound + up_bound)
Value-Oriented Searching Rules

low_bound < target

R

S_1^1

S_1^2

S_{k1}

S_{k2}

S_{i2}

S_{i1}

purple: continue
red: stop
blue: unknown area
Value-Oriented Searching Rules

![Diagram of searching rules]

- `S^1_1`, `S^2_2`, `S^k_2`
- `R`
- Low bound > target

Colors:
- Purple: continue
- Red: stop
- Blue: unknown area
Value-Oriented Searching Rules

- \( S_1 \)
- \( S_2 \)
- \( S_3 \)
- \( S_4 \)
- \( S_5 \)

Continue:
- \( S_1 \)
- \( S_2 \)
- \( S_3 \)
- \( S_4 \)
- \( S_5 \)

Stop:
- \( S_1 \)
- \( S_2 \)
- \( S_3 \)
- \( S_4 \)
- \( S_5 \)

Unknown Area:
- \( S_1 \)
- \( S_2 \)
- \( S_3 \)
- \( S_4 \)
- \( S_5 \)

\[ \text{low_bound} < \text{target} \]
Value-Oriented Searching Rules

low_bound < target

continue
stop
unknown area
Value-Oriented Searching Rules

After each round increase
\[ \text{target} = \text{target} + C \]

- continue
- stop
- unknown area
## Multi-Voltage Assignment Results

<table>
<thead>
<tr>
<th>Test benches</th>
<th>Power [2]</th>
<th>Power VOB</th>
<th>Ratio</th>
<th>Average No. of cells with Different Voltages</th>
</tr>
</thead>
<tbody>
<tr>
<td>n10</td>
<td>202709</td>
<td>185270</td>
<td>91.4%</td>
<td>1.7</td>
</tr>
<tr>
<td>n30</td>
<td>162534</td>
<td>155853</td>
<td>95.9%</td>
<td>2.9</td>
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<tr>
<td>n50</td>
<td>166931</td>
<td>157163</td>
<td>94.1%</td>
<td>7.8</td>
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<tr>
<td>n100</td>
<td>137608</td>
<td>126855</td>
<td>92.2%</td>
<td>9.9</td>
</tr>
</tbody>
</table>

VOBB: Our Value-Oriented Branch and Bound

## Multi-Voltage Assignment Results

<table>
<thead>
<tr>
<th>Test Benches</th>
<th>Power</th>
<th>Runtime</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VOB</td>
<td>VOB</td>
<td></td>
</tr>
<tr>
<td>n10</td>
<td>169058</td>
<td>169058</td>
<td>1.2 s</td>
</tr>
<tr>
<td>n30</td>
<td>143460</td>
<td>143460</td>
<td>12.1 s</td>
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<tr>
<td>n50</td>
<td>138983</td>
<td>138983</td>
<td>35.0 s</td>
</tr>
<tr>
<td>n100</td>
<td>113231</td>
<td>*117761</td>
<td>10.0 m</td>
</tr>
<tr>
<td>n200</td>
<td>*119229</td>
<td>*116341</td>
<td>10 h</td>
</tr>
<tr>
<td>n300</td>
<td>142641</td>
<td>*143041</td>
<td>32.4 m</td>
</tr>
<tr>
<td>Average</td>
<td>137767</td>
<td>138107</td>
<td>-</td>
</tr>
</tbody>
</table>

Floorplanning

- VOBBC-FP
  - Initial Floorplan
  - Optimal Voltage Assignment (VOBB)
  - Second Floorplan
  - Final Optimal Voltage Assignment (VOBB)
## Floorplanning Results

<table>
<thead>
<tr>
<th>Test Benches</th>
<th>Power Cost with Level Shifters(P)</th>
<th>Power Network Routing Resources</th>
<th>Level Shifter Number</th>
<th>Dead Space (%)</th>
<th>Wire Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>n10</td>
<td>169058</td>
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<td>1626</td>
<td>1584</td>
<td>94</td>
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<tr>
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<td>161464</td>
<td>1690</td>
<td>1806</td>
<td>30</td>
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<tr>
<td><strong>Average</strong></td>
<td><strong>138099</strong></td>
<td><strong>151219</strong></td>
<td><strong>1525</strong></td>
<td><strong>1611</strong></td>
<td><strong>39</strong></td>
</tr>
</tbody>
</table>

Conclusions

- This work is a major extension over the previous work [2]. The work [2] requires continuous delay domain, while this work removes this restriction.

- We show that the general MVA problem under timing constraints can be solved optimally by our value-oriented branch-and-bound based algorithm in a reasonable amount of time.
Thanks