Chapter 5

Placement of Relative Temperature Sensor

5.1 Problem Formulation of Placement

Given a set of thermal data, our objective is to place *HBJT*s, *RBJT*s and *CORE*s so that minimum error of temperature difference between hot spots and reference location is achieved. Before we formally define the problem, the following notations are given:

grid k: the *kth* grid location,

R_{jk}: the *jth RBJT* at *grid* k,

C_{jk}: the *jth CORE* at *grid* k,

H_{ijk}: the *ith HBJT* in the *cluster* j at *grid* k,

cluster j: the *jth* relative temperature sensor which consists of 1 R_{jk_1}, 1 C_{jk_2} and 4 H_{ijk_3}, for $1 \leq j \leq 4$ and k_1, k_2, k_3 are grid locations.

First, from our sensor architecture presented in Chapter 4, *CORE*s should be placed at a location where temperature fluctuation is small. Therefore, temperature gradient of *CORE* by Eq. (5.1) should be minimized.

$$F_1(C_j) = \min_{k \in grids} \bigtriangledown T(C_{jk}), j = 1, \cdots, n \tag{5.1}$$

where n is the number of clusters (the number of relative temperature sensors) and k specifies a grid location.

Second, the gradient of temperature difference between $RBJT$ and $CORE$ in the same cluster should be minimized to reduce temperature difference impacts on circuitry. Henceforth Eq. (5.2) is formulated.

$$F_2(R_j, C_j) =$$

$$\min_{k_1,k_2 \in grids} \bigtriangledown (T(R_{jk_1}) - T(C_{jk_2})), j = 1, \cdots, n \tag{5.2}$$

where $T(R_{jk_1})$ and $T(C_{jk_2})$ represent temperatures of $RBJT$ at $grid\,k_1$ and $CORE$ at $grid\,k_2$.

Third, in order to response the temperature fluctuation in hot spots, the $CORE$ should be placed along the path of $CORE$ to $HBJT$s which has the maximum temperature gradient. Henceforth Eq. (5.3) is defined.

$$F_3(H_{ij}, C_j) =$$

$$\min_{k_1,k_2 \in grids} \sum_{i=1}^{m} \frac{1}{\Delta T(H_{ijk_1}; C_{jk_2})}, \tag{5.3}$$

$$j = 1, \cdots, n$$

where Eq. (5.3) represents inverse of temperature difference between $HBJT$s and $CORE$s.

Next, the distance from $RBJT$ to $CORE$ and the distance from $HBJT$ to $CORE$ should be as balanced as possible. Therefore, Eq. (5.4) is defined.

$$F_4(R_j, C_j, H_{ij}) =$$

$$\min_{k_1,k_2,k_3 \in grids} \sum_{i=1}^{m} (||R_{jk_1}; C_{jk2}||_2 - ||H_{ijk_3}; C_{jk_2}||_2), \tag{5.4}$$

$$j = 1, \cdots, n$$

where $||x; y||_2$ is manhattan distance of x to y, n is the number of clusters and m is the number of *HBJT*s in a cluster. In our design, $m = 4$.

Finally, by Eq. (5.5), it requires that the total distance should be minimized.

$$F_5(R_j, C_j, H_{ij}) =$$

$$\min_{k_1,k_2,k_3 \in grids}(||R_{jk_1}; C_{jk_2}||_2 + \sum_{i=1}^{m} ||H_{ijk_3}; C_{jk_2}||_2), \tag{5.5}$$

$$j = 1, \cdots, n$$

To take the above six equations into consideration, for a cluster (a relative temperature sensor), we define a cost function to evaluate a placement of *HBJT*s, *RBJT* and *CORE* as follows.

$$\sum_{t=1}^{5} W_t * F_t \tag{5.6}$$

where W_t, $t = 1, \cdots, 5$ are weighting factors and F_t, $t = 1, \cdots, 5$ are various functions defined by Eq.'s (5.1) to (5.5).

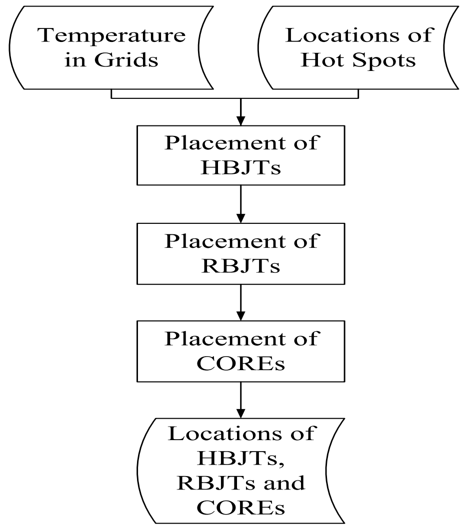

Figure 5.1: Design flow of relative temperature sensor placement

5.2 Proposed Algorithm

In order to approximate the optimal locations of *relative* temperature sensors, we conduct the placement of *relative* temperature sensors in 3 steps: placement of *HBJT*s, placement of *RBJT*s and placement of *CORE*s as shown in Fig. 5.1. The goal of placing *HBJT*s is to minimize temperature error between *HBJT*s and hot spots for all benchmarks. The goal to place *RBJT*s is to identify temperature stable grids so that Eq. (5.7) is minimized. Finally, the goal to place *CORE*s is to identify grids so that the grids have small temperature fluctuation (Eq. (5.1), Eq. (5.2)), the distance from *RBJT* to *CORE* and the distance from *HBJT*s to *CORE* is balanced (Eq. (5.4)), and the total wire length is minimized (Eq. (5.5)).

Before we describe the details of the first step, we give the following assumptions. Assume a given floorplan consists of b blocks and p sets of benchmarks. First, *SimpleScalar* [11] generates p sets of test vectors by simulating benchmarks. Second, *Wattch* [5] estimates the power consumption of each block by simulating test vectors. Next, the power consumption information is fed to *HotSpot* [4], a thermal model tool, to identify hot spots and compute temperature information. We assume that our placement of *relative* temperature sensor will take all benchmarks into consideration in one time. Hence, we will have $b*p$ hot spots (each benchmark reports b hot spots and we have p benchmarks). We also assume each block is guarded by one *HBJT*.

Therefore, the first step of placing *HBJT*s is to select b locations so that $b*p$ hot spots can be detected by b *HBJT*s. In this step, K-mean clustering algorithm [1] is utilized where b clusters are formed. One *HBJT* is placed at the center of a cluster to assure minimum temperature difference between *HBJT*s and hot spots.

The second step is to place *RBJT*s. The location of *RBJT* is strongly related to locations of the other 4 *HBJT*s in the same cluster because they share the same *CORE*. Since we have b *HBJT*s, there will be $\lceil \frac{b}{m} \rceil$ *RBJT*s, where m is 4 in our design and $\lceil \quad \rceil$ is ceiling function. One *RBJT* and four *HBJT*s will form a cluster (together with a *CORE* forms a *relative* temperature sensor).

Placing of *RBJT* is conducted in 2 steps. First, based only on the distance among *HBJT*s, Quality-Threshold (QT) clustering [10] is used to form groups, where each group contains 4 *HBJT*s. Then, the center of 4 *HBJT*s is computed. Based on this center and the clustering result produced by QT algorithm, K-mean clustering algorithm is called to refine the initial result. In this refinement process, the same distance cost is used. After the K-mean clustering algorithm is completed, we have groups of *HBJT*s. For each group j, we find the position of its *RBJT* (denoted as R_j). For R_j at grid location k, the following cost function is computed.

$$Cost(j,k) = \alpha \times RF_1 + \beta \times RF_2 \tag{5.7}$$

where RF_1 is defined to be the temperature gradient of R_j at grid k. RF_2 is the total distance from R_j to the other four *HBJT*s. α, β are weighting factors to control the relative importance of RF_1 and RF_2. In this case, α is set to be much larger than β. RF_1 is the same as F_1 defined in Eq. (5.1). RF_2 is defined as

$$RF_2 = \sum_{i=1}^{4} ||R_{jk}; H_i||_2 \tag{5.8}$$

where R_{jk} denotes that R_j at grid k position, H_i is the grid position of *HBJT* found in the first step and $||R_{jk}; H_i||_2$ is the manhattan distance from R_{jk} to H_i. This term is used to prevent *RBJT* from being moved too far away *HBJT*s.

The cost function is computed for all grid positions. The one with the least cost is chosen for the *RBJT* in group j. For n groups (n *relative* temperature sensors), n iterations will be called.

The final step is to place *CORE*s. Now the locations of one *RBJT* and four *HBJT*s in a cluster are known. For each cluster, the location of *CORE* is searched by computing the cost function defined in Eq. (5.6) for all grids given the locations of *RBJT* and *HBJT*s in the same cluster.