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Full Length Research Paper

Minimize network congestions in single-row networks

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Single-row routing is a technique for routing pair of nodes arranged in a single-row axis or set of nets. The nets make up the wire without crossing each other in the printed circuit board design which is drawn from left to right. The main objective in single-row routing is to achieve the optimal results of minimum congestion arising from the number of horizontal tracks in the network. Optimal results for a single layer network have been achieved through a model called enhanced simulated annealing for single-row routing (ESSR). However, a single layer model suffers from non-tolerable lower bound values with high congestion depending on the network size. These results may further be improved by partitioning the network into two or more layers. In this paper, a technique based on the graph clustering concept for partitioning the nodes from a single-row network into several layers of planar graphs by using k-means algorithm has been proposed. The experiment result shows that the proposed technique is able to minimize the network congestions.

Key words: Enhanced simulated annealing for single-row routing (ESSR), graph clustering, k-means algorithm, single-row routing.

INTRODUCTION

The layering and routing is the main problems in designing a complex multilayer printed circuit board (PCB) for efficient electronic systems. Normally, if the traditional routing algorithm cannot handle these challenges effectively, the manual routing effort will be implemented (Ozdal and Wond, 2004). Shaharuddin (2009), proposed single-row routing technique used traditionally employed for designing the routes between the electronic components of a PCB. Due to its interval-matching capability, it is also possible to extend the technique to other applications involving pair matchings, such as in channel assignments in the cellular telephone networks. The PCB routing problems becomes more challenging when the circuit complexity is increased. The single-row routing is one of the routing methods in designing the PCB.

To illustrate a single-row routing problem, assume a set of nodes that represents as an electrical components, $V = \{1,2,3,...,n\}$ is arranged horizontally along a single-row axis from left to right. Each net in the single-row routing consist of two nodes. The net represent the conductor paths that exist between nodes. Single-row routing was used to route a net list $L = \{N_1, N_2, N_3,..., N_m\}$ with minimum number of tracks and the nets are not allowed to cross each other (Fred and Jain, 2002). The objective is to find the optimum wiring from a set of pins which are aligned in a single node axis such that there is non-intersection wire on each layer. If there is an intersection wire on each layer or close to each other, the electro-magnetic interference will occur, which can generate intolerable amount of heat, and electric and magnetic fields. Basically, graph theoretic is used widely in this problem.

An ESSR model was proposed to obtain the optimum single-row network (Salleh et al., 2002). The simulated annealing technique is use to develop this algorithm.

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The ESSR model is used to design the single-row routing realization. The single- row routing technique was applied to design the route of wires to ensure that each electronic component could communicate with each other.

The single-row routing problem can be put in the context of a single-layer PCB. The design of multi-layer printed circuit boards is important for construction of complex electronic systems (Zomaya et al., 2004). This has led to the use of graph clustering methods for partitioning the wires into several layers.

In this paper proposed a new technique based on graph clustering by using k-means algorithm in order to the single-layer problem. The ESSR is use to obtain the optimum single-row network and also can minimize the doglegs or inter-street crossing in nets.

The rest of this paper is structured as follows. First, the related works of single-row routing, such as technique use in single-row routing, were given, after which the techniques were used to minimize the network congestion explained in technique description. The ESSR model was used to produce the experiment results, before the discussions and conclusions were finally given.

RELATED WORKS

Graph clustering is the task of grouping the vertices in a graph into clusters taking into consideration the edge structure of the graph in such a way that there should be many edges within each cluster and relatively few between the clusters (Schaeffer, 2007). Many approaches have been proposed to solve the graph clustering problem such as center based clustering algorithm (Babak et al., 2010), k-means (Bhatia, 2004), spherical k-means (Zhong, 2005) and Tabu k-harmonic means (Gungor and Unler, 2008).

The center based clustering algorithm is one of the popular classes of data clustering algorithms. K-means algorithm is one of the most popular algorithms for clustering (Berkhin, 2002) due to its simplicity and high speed in clustering large data set. The standard k-means in Equation (1) was used to minimize the mean-squared error:

$$E = \frac{1}{N}\sum_{x}\left\|x-\mu_{k(x)}\right\|^{2}$$
(1)

where: $k(x) = \arg \min_{k \in \{1,\ldots,K\}} \left\|x-\mu_{k(x)}\right\|^{2}$ is the index of the closest cluster centroid to x, N is the total number of data vectors. Fred and Jain (2002) claim that k-means algorithm is the simplest clustering algorithm, since it is computationally efficient and does not require the specifications of many parameters. In addition, they suggest the use of two parameters which are the number of clusters, k for the k-means algorithm, and t, the threshold on the dendrogram produced by the single-link (SL) method.

The procedure of k-means algorithm follows a simple way to classify a given data set through a certain number of clusters, k. It starts with a random initial partition and the designer determined the number of clusters. One k centroids will be defined for each cluster. The next step is to take each point belonging to a given data set and associate it to the nearest centroid. The sum of squared Euclidean distances measures has been adopted in most of the studies related to these algorithms due to its computational simplicity. The new centroids of each group need to recalculate based on these new memberships by taking the average of these members. Then, a new binding has to be done between the same data set points and the nearest new centroid. A loop has been generated. The location of k centroids is changed step by step until there are no more changes. This might be noticed when the loop has ended. In other words centroids do not move any more (Hartigan and Wong, 1979). Ng MK (2000) extended the k-means algorithm for clustering data sets with the fixed number of objects in each cluster.

Bhatia (2004), introduce a new algorithm to perform adaptive k-means clustering and shows it is not dependent on the selection of K seeds to initialize the clusters. Zhong (2005), investigate the spherical k-means algorithm for each document as well as each cluster as a high unit-length vector. Due to unsupervised document organization, automatic topic extraction, and fast information retrieval and filtering, the document clustering has become an increasingly important technique. Laszlo and Mukherjee (2007) used a genetic algorithm for selecting centers to seed the k-means clustering algorithm. Gungor and Unler (2008) solved the initialization problem trapping to the local minima of K-Harmonic mean clustering based on tabu search technique.

In this paper, it states that the surface mount technology (SMT) machine inserts electronic components into defined positions on a PCB and the components are supplied from a set of reels each containing a tape of identical electronic components. Because of the limited capacity of feeder bank, the electronic assembly plant uses multiple assembly to produce PCBs with number of types of components being greater than the maximum number of reels, that is, more than one assembly process in the PCB insertion problem. An approached is develop by adding suitable constraints into the mathematical formulation on k-means algorithm and applies it into the printed circuit board insertion problem.

TECHNIQUE DESCRIPTION

Here, we describe a new technique that has been developed. We are given a net list $L = \{N_1, N_2, N_3, ..., N_{10}\}$ and each net are forms from pairs of pins showed in Figure 1.

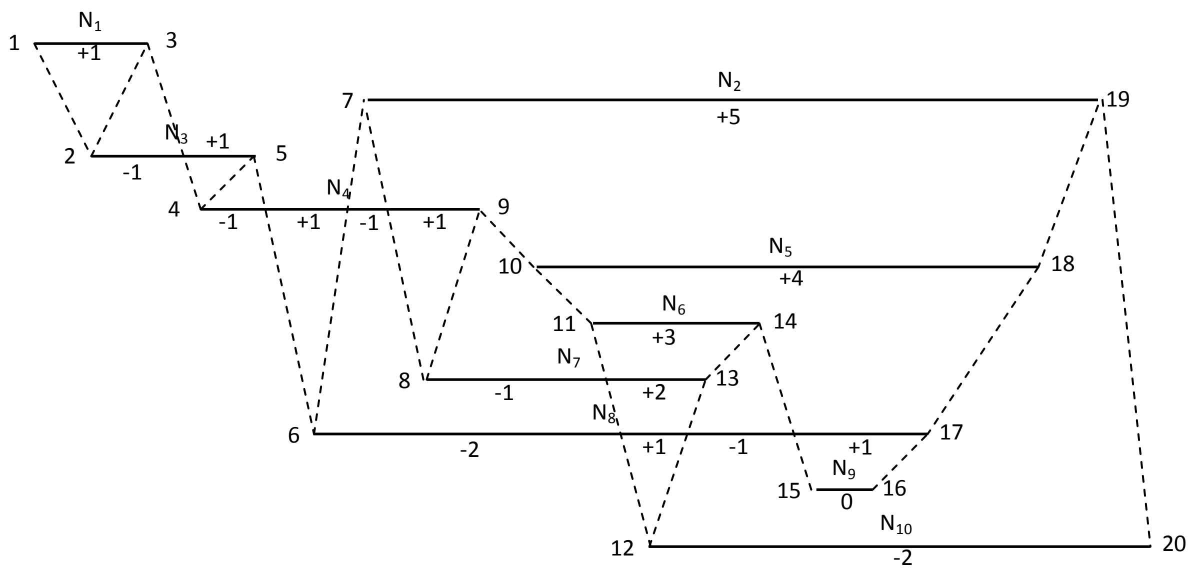

Figure 1. Net list $L = \{N_1, N_2, N_3, ..., N_{10}\}$.

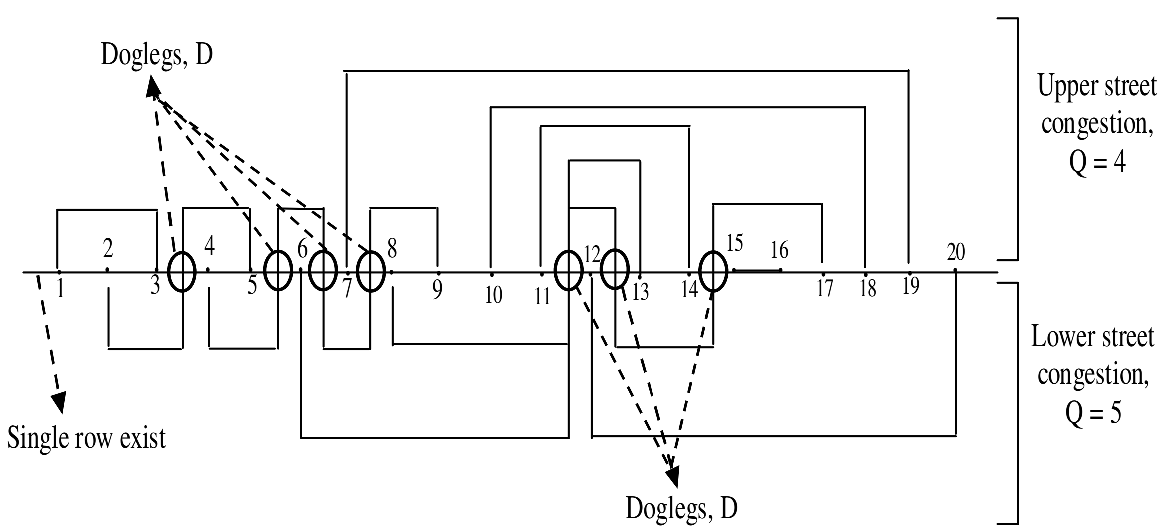

Figure 2. The single-row routing problem terminologies.

In ESSR, each nets ordering has their own energy and it is a function of the street congestion Q and number of doglegs D. The energy function is expressed as the total lengths of all tracks as follows:

$$E = f(Q, D) = \sum_{i=1}^{m} \sum_{r=1}^{m_i} | h_{i,r} | \qquad (2)$$

In Equation (2), $h_{i,r}$ is the height of segment r in net i, while m is the number of nets and m_i is the number of segments in the net N_i, for $i = 1,2,...,m$. The number of overall street congestion and the number of z doglegs are denoted by Q and D respectively (Shaharuddin and Nor Haniza, 2009). The doglegs are inter-street crossing. Figure 2 shows the terminologies of the single-row routing problems. The input are $N_1(1,3)$, $N_2(7,19)$, $N_3(2,5)$, $N_4(4,9)$, $N_5(10,18)$, $N_6(11,14)$, $N_7(8,13)$, $N_8(6,17)$, $N_9(15,16)$, $N_{10}(12,20)$.

Based on Figure 2, the area above the single-row axis is called as upper street and below the single-row axis is called as lower street. In defining the overall street congestion Q is based on the maximum path of nets of its upper and lower street congestions, that shows as $Q = \max\,(Q_{upper}, Q_{lower})$. So, the overall street congestions are 5. And the doglegs equal to 8.

The single-row routing representation of ten nets in a single layer, obtained by using ESSR model, is shown in Figure 3 where $E = 29, Q = 5, D = 8$.

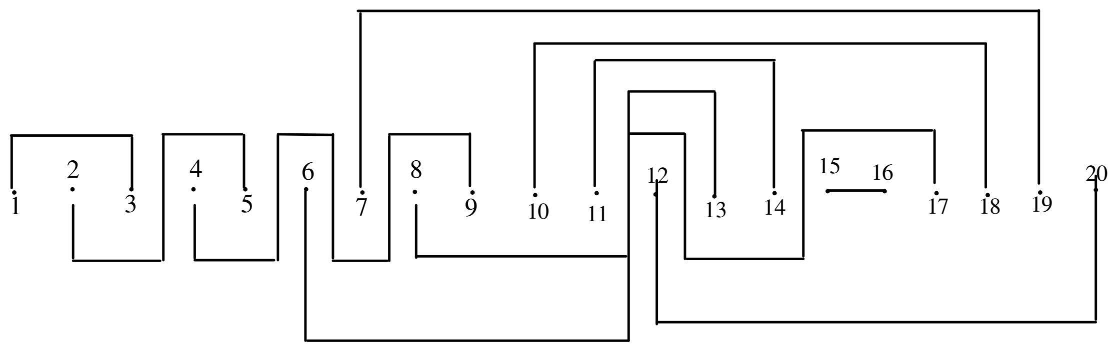

Figure 3. Single-row routing realization of L

Table 1. The initial list of L_0 nets.

N_i	b_i	e_i	E	D
N_1	1	3	1	0
N_2	7	19	5	0
N_3	2	5	2	1
N_4	4	9	4	3
N_5	10	18	4	0
N_6	11	14	3	0
N_7	8	13	3	1
N_8	6	17	5	3
N_9	15	16	0	0
N_{10}	12	20	2	0
	Total		E= 29	D=8

The initial list of L_0 nets, L_0= {N_1, N_2, N_3, N_4, N_5, N_6, N_7, N_8, N_9, N_{10}} are shown in Table 1. In Table 1, N_i is represented as the number of net i; b_i is the beginning pin in N_i; e_i is the ending pin in N_i; E is the energy that is produced in each nets, and D is the doglegs that exist in each pair of the nets.

In producing the energy, overall street congestion and the number of doglegs will be decrease in nets when using the ESSR simulation model. The problem is to find a partition of L into a number of subsets $L_1, L_2, ..., L_T$ such that each partition $L_i (i = 1,2,..,T)$ can be realized on a single layer. The nets are to be realized by single row routing by the use of non-overlapping wires that are composed solely of horizontal and vertical segments.

Using k-means for layer division

The number of cluster, k is equivalent to the number of cliques in the containment graph. In graph theory, a clique in an undirected graph G = (V, E) is a subset of the node set $C \subseteq V$, such that for every two nodes in C, there exists an edge connecting the two.

Multi-layer realization

The multi-layer realization ensures that there are no intersections between wires in net lists. It also can reduce the congestions in the nets.

RESULTS

The results are produced based on the net lists shown in Figure 1. There are ten uses of nets which show that the value of E = 29, Q = 5, and D = 8. Using ESSR, the annealing process will be done to decrease the value of energy, in that E can minimize both the overall street congestion, Q, and doglegs, D, when the position of a sets of nets in the list were swapped in the single-layer network. Figure 4(a) shows the net list for the first move, where L_1 = {N_2, N_5, N_1, N_9, N_4, N_6, N_{10}, N_3, N_7, N_8}. The value of E has decrease to 21 and both value of Q and D also decrease to 4 and 5. Figure 4(b) shows the realization for L_1 for the first move.

Table 2 shows the value of E and D that has change after first move for each net. The net N_4 has 2 doglegs,

net N_{10} has 3 doglegs and others do not have any doglegs.

The last move of the net list is shown in Figure 5(a) where L_2 = {N_2, N_5, N_1, N_7, N_4, N_{10}, N_3, N_9, N_6, N_8} have

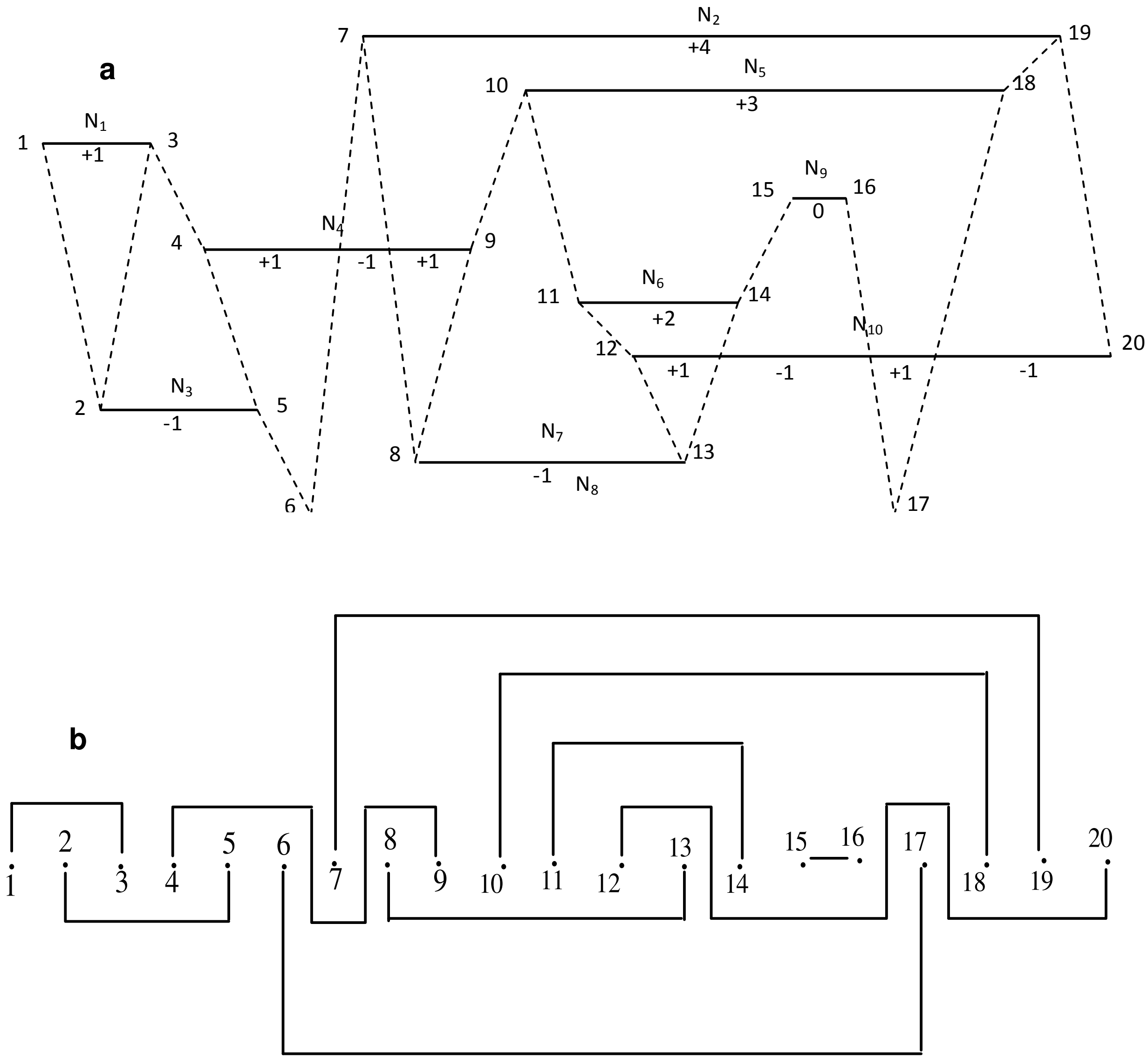

Figure 4. (a) Nets ordering (list) having E = 21, Q=4 and D = 5, and (b) Realization for the L_1 for the first move.

Table 2. First move with L_1= {N_2, N_5, N_1, N_9, N_4, N_6, N_{10}, N_3, N_7, N_8}.

N_i	b_i	e_i	E	D
N_1	1	3	1	0
N_2	7	19	4	0
N_3	2	5	1	0
N_4	4	9	3	2
N_5	10	18	3	0

N_6	11	14	2	0
N_7	8	13	1	0
N_8	6	17	2	0
N_9	15	16	0	0
N_{10}	12	20	4	3
Total			E = 21	D = 5

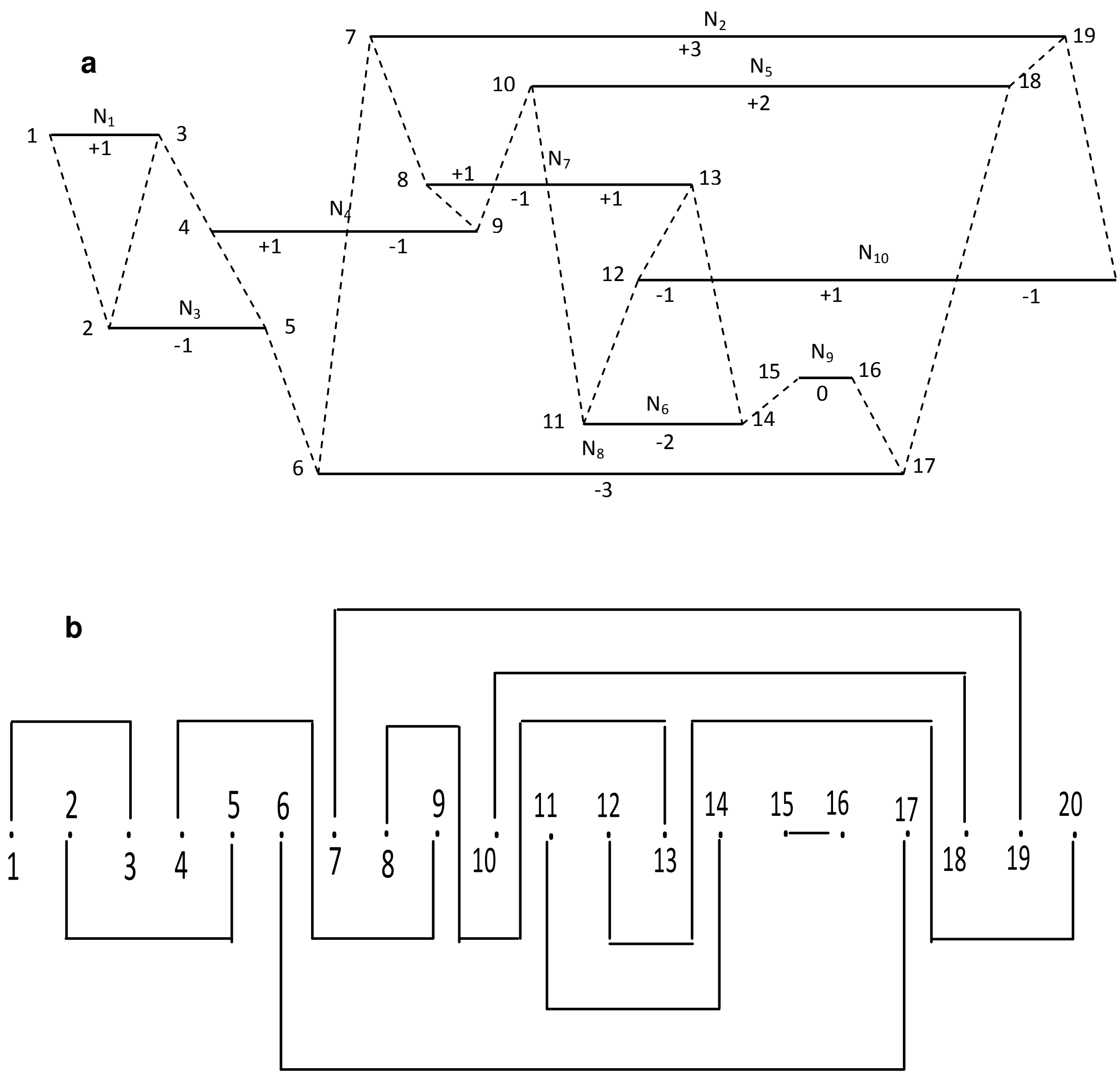

Figure 5. (a) Net lists ordering having E = 20, Q = 3, and D = 5, and (b) Realization of L2 for the last move.

decrease the value of energy, the overall street congestions and doglegs which is $E = 20, Q = 3, D = 5$. Figure 5(b) shows the final realization of net L_2. The value of E and Q is decrease and the value of the D is still the same with previous value.

Table 3 shows the value of E and D for each net of $L_2 = \{N_2, N_5, N_1, N_7, N_4, N_{10}, N_3, N_9, N_6, N_8\}$.

This output is obtained by applying ESSR model. In this case, the value of energy, E is reduced to 20 when the network is transformed into multi-layer compared to 29 in single-layer. The overall street congestion also decrease to 3 from 5 in single-layer and doglegs value also decrease from 8 in single-layer to 5. The doglegs for

the last move were used to achieve the maximum value even
when the annealing process was carried on it.

DISCUSSION

The 10 nets used in this study were tested on ESSR to find the optimum results on single-row routing. Every set

of a nets list will moved or swap until it achieve the most lowest value of energy, E, overall street congestion, Q and doglegs, D in single-row routing. Based on the previous results, the initial value of E, Q and D are 29, 5, and 8. After the annealing process is done, the value of E, Q and D are decrease to 21, 4, and 5. Then the annealing process will be done again until it achieves the maximum

Table 3. Second and last move with L_2= {N_2, N_5, N_1, N_7, N_4, N_{10}, N_3, N_9, N_6, N_8}.

N_i	b_i	e_i	E	D
N_1	1	3	1	0
N_2	7	19	3	0
N_3	2	5	1	0
N_4	4	9	2	1
N_5	10	18	2	0
N_6	11	14	2	0
N_7	8	13	3	2
N_8	6	17	3	0
N_9	15	16	0	0
N_{10}	12	20	3	2
Total			E = 20	D = 5

move the set of nets list. The value of the single-row routing last move is $E = 20, Q = 3, D = 5$. And the doglegs have achieved its maximum values.

CONCLUSIONS

This paper shows how to use k-means algorithm within the layering problem of single-row routing. The algorithm for clustering the net lists into several layers has been presented. The wiring of single-layer PCB is more congested rather than the multi-layer PCB of the same network. By using this technique, the congestion could be reduced even in a large network.

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