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Reducing network congestion by separating nets of single-row networks into layers

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Abstract

Single-row routing is a method for routing pair of nodes set in a single-row axis. The nets construct the wire without traverse each other in the printed circuit board design that has been drawn from left to right. The main purpose in single-row routing is to achieve the optimal results of minimum congestion arise 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 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 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.

Keywords : ESSR, graph clustering, k-means algorithm, single-row routing.

1. Introduction

The layering and routing is the main problems in designing a complex multilayer Printed Circuit Board (PCB) for proficient electronic systems. In [1], single-row routing is one of the techniques used conventionally employed for designing the routes between electronic components of a printed-circuit board (PCB). The PCB routing problems becomes more challenging when the circuit complexity is increased [2, 3, 17]. 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, $V = \{1,2,3,\ldots,n\}$ is prearranged horizontally along with 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 is

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deployed to route a net list $L = \{N_1, N_2, N_3, \ldots, N_m\}$ with minimum number of tracks and the nets are not allowed to cross each other [4]. 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. Basically, graph theoretic is used widely in this difficult situation.

An Enhanced Simulated Annealing Single-row Routing (ESSR) model was proposed to obtain the optimum single-row network [5]. The simulated annealing technique is used to build up this algorithm. In ESSR, the energy function is expressed as the total lengths of all tracks as follows

$$E = \sum_{i=1}^{m} \sum_{r=1}^{m_i} | h_{i,r} | \tag{1}$$

In Eq. (1), $h_{i,r}$ 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 $i = 1, 2, \ldots, m$. The number of overall street congestion and the number of doglegs are denoted by Q and D respectively [5]. The doglegs are inter-street crossing.

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 [4, 3]. This has led to the use of graph clustering methods for partitioning the wires into several layers. This paper proposed a new technique based on graph clustering by using k-means algorithm in order to solve it.

Section 2 elaborates the related works of single-row routing. The technique uses to minimize the network congestion is explained in Section 3. The ESSR model is used to produce an experiment results given in Section 4, followed by the conclusion in Section 5.

2. 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 [6, 7]. Many approaches have been proposed to solve the graph clustering problem such as center based clustering algorithm [8], k-means [0, 11], spherical k-means [10] and Tabu k-harmonic means [5].

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 [8], [10], [11] due to its simplicity and high speed in clustering large data set. In [10] shows the standard k-means equation (2) to minimize the mean-squared error

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

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 claim that k-means algorithm is the simplest clustering algorithm [13] since it is computationally efficient and does not require the specifications of many parameters. There are two parameters used in 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 are changed step by step until no more changes are done might be noticed when loop has finished. In other words centroids do not move any more [13].

In 2000, Ng extended the k-means algorithm for clustering data sets with the fixed number of objects in each cluster [4]. In [4], the Surface Mount Technology (SMT) machine inserts electronic components into defined positions on a Printed Circuit Board (PCB) and the components are supplied from a set of reels each containing a tape of indentical 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, i.e., 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 apply it into the printed circuit board insertion problem.

Unler and Gungor (2008) solved the initialization problem trapping to the local minima of K-Harmonic mean clustering based on tabu search technique [5, 16]. Laszlo and Mukherjee presented a genetic algorithm for selecting centers to seed the k-means clustering algorithm [6, 15]. In [11] it presented an algorithm to perform adaptive K-means clustering and shows it is not dependent on the selection of K seeds to initialize the clusters. In [12], the spherical k-means algorithm represented 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. In [12] cited the clustering method can be used to automatically group the retrieved documents into a list of meaningful categories.

3. Technique Description

This section describes a new technique that has been developed. We are given a net list $L = \{N_1, N_2, N_3, ..., N_{10}\}$ in Figure 1. The single-row routing representation of these nets in a single layer which is obtained by using ESSR model is shown in Figure 2 where $E = 44, Q = 4, D = 16$.

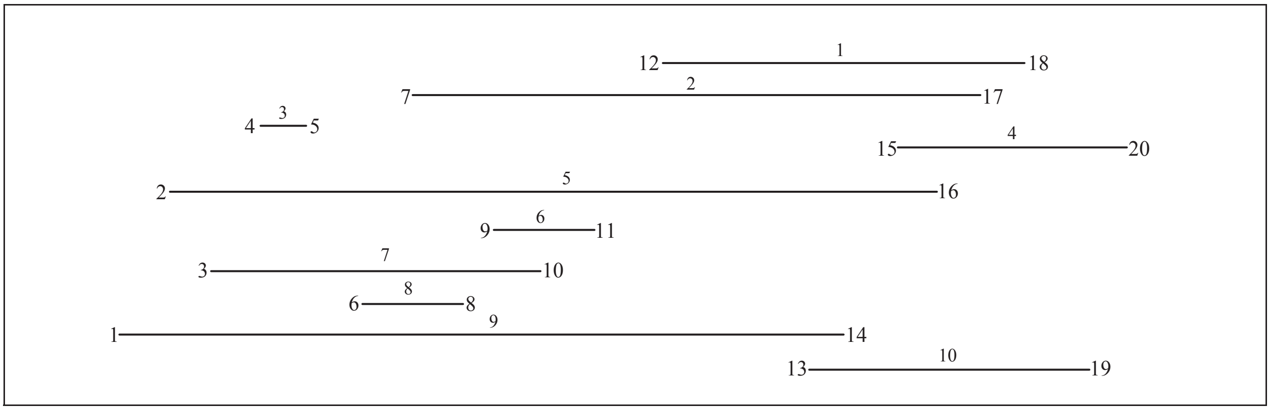


Figure 1. Net list $L = \{N_1, N_2, N_3, ..., N_{10}\}$

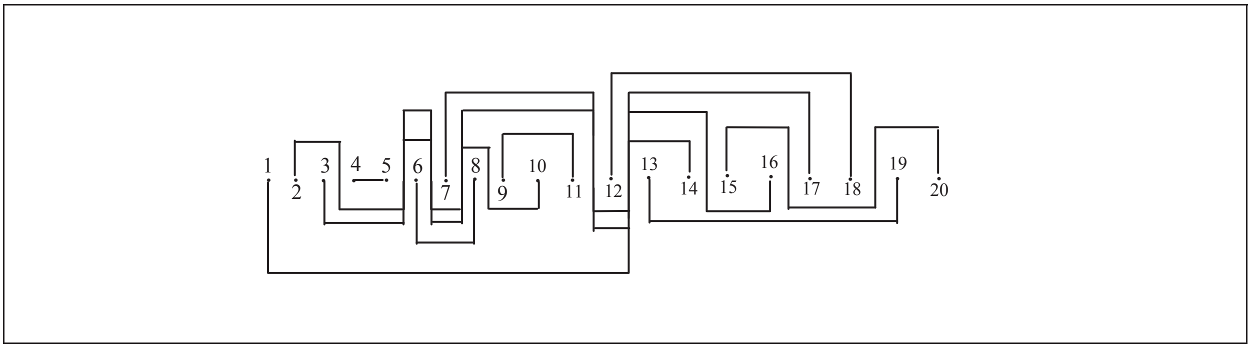


Figure 2. Single-row routing realization of L

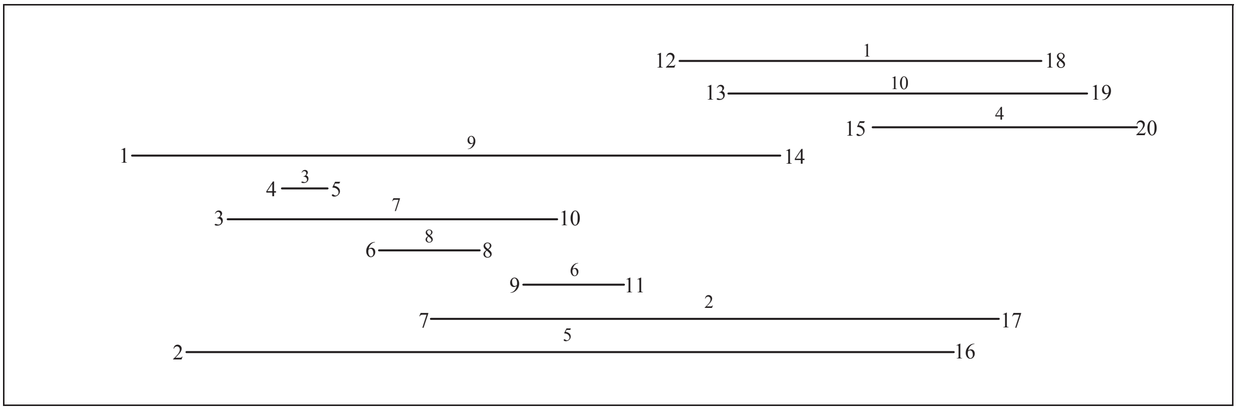
The problem is to find a partition of L into a number of subsets $L_1, L_2, \ldots, L_T$ such that each partition $L_i (i = 1,2,..,T)$ can be realized on a single layer. The nets are to be realized by single row routing by the use of non-overlapping wires that are composed solely of horizontal and vertical segments.

Using K-means for Layer Division

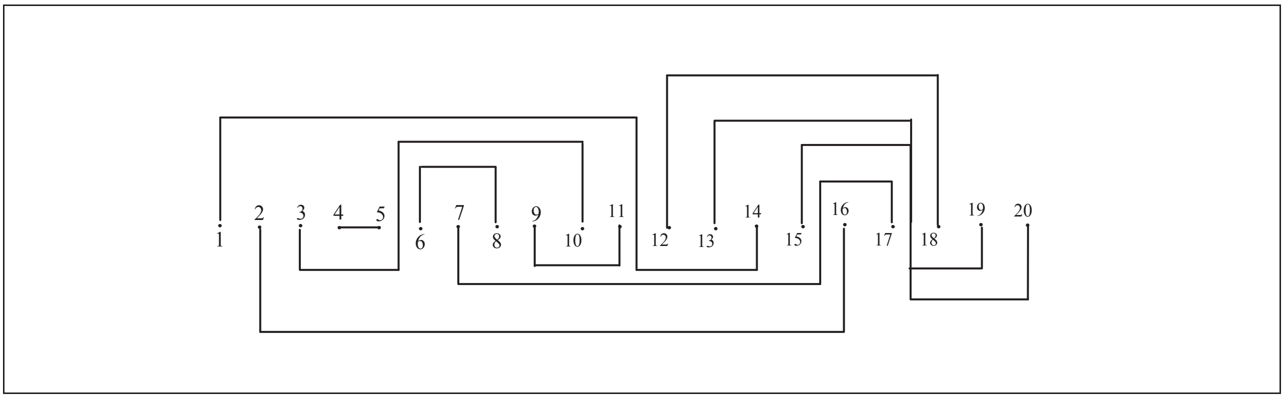
The number of cluster, k is equivalent to the number of cliques in the containment graph. In graph theory, a clique in an undirected graph G = (V, E) is a subset of the node set $C \subseteq V$, such that for every two nodes in C, there exists an edge connecting the two.

Multi-layer Realization

The multi-layer realization is to ensure that there are no intersections between wires in net lists. The Figure 3 show the first move of $L_1 = \{N_1, N_{10}, N_4, N_9, N_3, N_7, N_8, N_6, N_2, N_5\}$ having $E = 27, Q = 4, D = 5$.



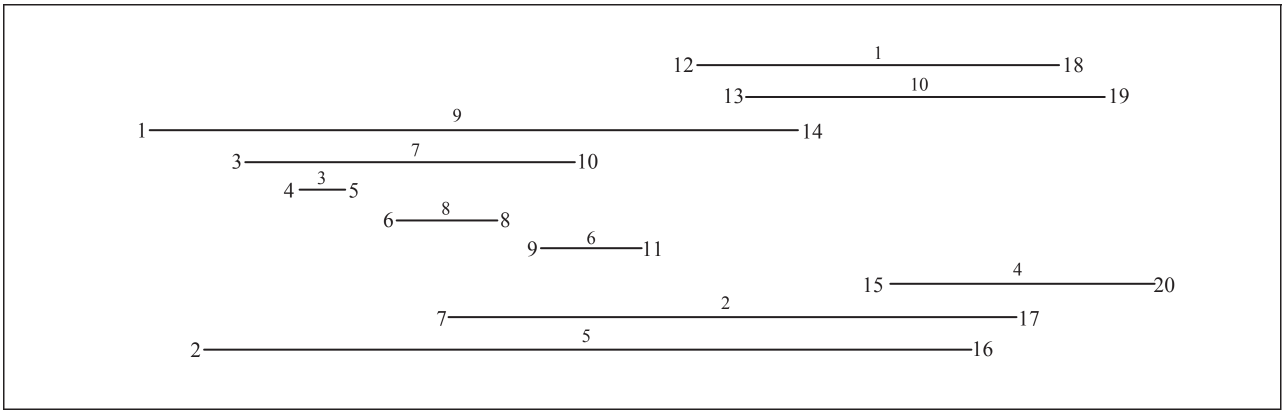
(a)



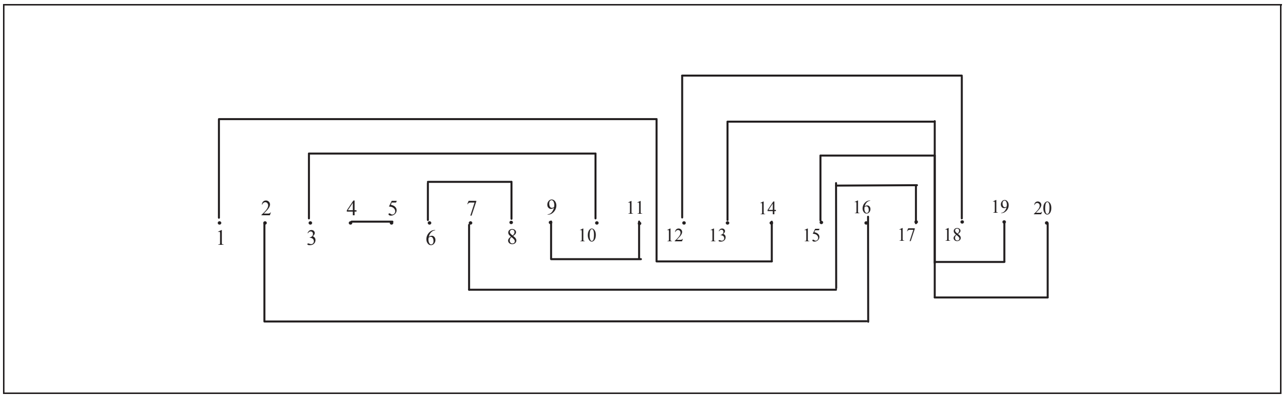
(b)

Figure 3. (a) Nets ordering (list) and (b) Realization for the L_1 for the first move

The last move of the net list is shows in Figure 4 where $L_2 = \{N_1, N_{10}, N_9, N_7, N_3, N_8, N_6, N_4, N_2, N_5\}$ have $E = 26, Q = 4, D = 4$.



(a)



(b)

Figure 4. (a) Net lists ordering and (b) Realization of L2 for the last move

This output is obtained by applying ESSR model. In this case, the value of energy, E is reduced to 26 when the network is transformed into multi-layer compared to 44 in single-layer.

4. Results

Consider ten random data sets are generated to collect the data. The number of nets to be connected by single-row routing is shown in the first column in Table 1. Output obtained by using ESSR technique is in the form of energy E, overall street congestion Q and number of doglegs D which are shown in columns 6, 7 and 8 respectively. The value of E, Q, and D represents the total sum of the corresponding value for each layer. Each graph contains 6 to 42. In Table 1 shows the result of our experiment. The result shows that the energy in the single-layer network is reduced when the original problem is transformed into multi-layer representation.

Table 1. Result from the Simulations

#Nets	Single layer			Multi-layer		
	E	*Q*	*D*	*E*	*Q*	*D*
6	24	3	9	12	3	3
10	52	6	13	35	5	6
14	165	8	43	57	7	8
20	342	10	84	96	9	16
26	672	15	129	164	10	26
30	612	12	134	176	9	29

4	1482	22	231	347	15	55
38	1495	17	260	386	15	65
40	1662	18	276	448	14	77
42	1915	20	278	525	19	78

5. Conclusion

This paper presents on 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.

Acknowledgment

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