Cable Routing Problem Collection

Orion Sehn

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A plethora of problems come from finding optimal routes for electrical cables. A number of these have been explored, and a number I am unsure as to if they have been explored or not. These include variations on explored problems, or simplifications of real world problems which remain hard.

I'm starting this list to enable discussion on different related cable routing problems. To collect and define yet to be explored problems, and to provide a list of references to problems which have been explored.

1 Relevant Studied Problems

These are problems that I have found which have been explored, and are documented. I have included what references I could. Some of these are strictly copied from a wonderful compendium of problems from Hauptmann, Mathias and Karpinski, Marek [2] (I should really go back and cite the original work for some of these)

1.1 Fundamental problems

These are relevant, long standing, highly general problems which come up when considering addressing more complicated problems in cable routing. This section is included for reference.

1.1.1 Shortest Path Problem

Many variations on this problem exist ie. (directed graphs, negative weights, etc.) This definition is of an undirected graph with non-negative weights.

INSTANCE: Graph $G = (V, E)$, edge costs $c : E \rightarrow \mathbb{R}^+$, a source vertex v_1 and an destination vertex v_n.
SOLUTION: A path $P = (v_1, v_2, ..., v_n)$

COST FUNCTION: $\sum_{e \in P} c(e)$

OBJECTIVE: Minimize.

Hardness: Has the hardness P, due to existence of near linear algorithms including $O((E + V)logV)$ - Heap implemented Dijkstra [2].

1.1.2 Minimum Steiner Tree Problem

INSTANCE: Graph $G = (V, E)$, edge costs $c : E \rightarrow \mathbb{R}^+$, set of terminals $S \subseteq V$

SOLUTION: A tree $T = (V_T, E_T)$ in G such that $S \subseteq V_T \subseteq V$, $E_T \subseteq E$

COST FUNCTION: $\sum_{e \in E_T} c(e)$

OBJECTIVE: Minimize.

Approx: Approximable within $ln(4) + \epsilon < 1.39$

Hardness: NP-hard to approximate within an approximation ratio 96/95 [2]

Comment: Admits a PTAS in the special case when G is a planar graph. Solvable exactly in time $O(3kn + 2k(n \log n + m))$, where $n = |V|$ is the number of vertices, $k = |S|$ the number of terminals and $m = |E|$ the number of edges in the graph. [2]

1.1.3 Minimal Steiner Forest Problem

INSTANCE: Graph $G = (V, E)$, cost function $c : E \to R+$, set of k terminal pairs $S = (s_1, t_1), ..., (s_k, t_k)$

SOLUTION: A forest $F \subseteq E$ such that for all $1 \leq j \leq k$, vertices s_j and t_j are contained in the same connected component of F.

COST FUNCTION: $\sum_{e \in F} c(e)$

OBJECTIVE: Minimize.

Approx: Approximable within $2 - 1/k$ [2]

Hardness: NP-hard to approximate within 96/95 [2]

Comment: When G is a planar graph [2] obtained a PTAS.

1.2 Explored Problems

TBD

1.2.1 Voltage Drop Problem

1.2.2 Circuit Board Design

2 Undocumented Problems

This section includes problem definitions which I could not find, documented or studied elsewhere.

2.1 Cable Support Problems

Each of the following problems are related in that the instance they have begins with a graph and a set of source destination pairs for which a connected route must be found, and the objective is to minimize some cost function. A list of considerations and restrictions which are used to define variants of the problem are listed first, then a handful of particular variants of the problem.

2.1.1 List of cable support considerations/constraints

This is a list of considerations which may impact cable routing, and which may be included in an abstraction of a problem. The inclusion of these considerations may result in that abstraction of the problem being intractable. Some considerations may have a reduced impact on complexity, and so a relaxation is acceptable. Options for handling each consideration are provided in parenthesis roughly in an increasing order of complexity.

- Cable/Tray Costs: (only cable cost/only tray cost/1:1/tradeoff/individual costs by spec/material specific routing costs)
- Tray Fill Rate: (don't handle/disallow when full/allow paying cost for additional tray when full/allow paying additional cost + conduit friction restriction)
- Existing Tray: (no existing tray/existing tray)
- Voltage Categories: (no voltage categories/independent voltage categories/co-run voltage categories/voltage categories w. material+hours cost)
- Online Arrival of Cables: (offline/semi-online/online)
- Dynamic Environment: (static/dynamic)
- Jumper Cost: (no penalty/flat penalty/linear penalty/exponential penalty)
- Height: (no penalty/linear penalty/stepwise penalty/exponential penalty)
- Turn Cost: (no penalty/penalty each turn/variable penalty depending on angle of turn)

A combination of these variations on the problem may be chosen to make many different problems. A small collection of possible problem abstractions is defined below, to enable discussion and exploration of these problems.

2.1.2 Cable Support Problem

INSTANCE: Graph $G = (V, E)$, edge costs $c : E \to \mathbb{R}^+$, a set of source/destination pairs $S = (s_1, t_1), ...(s_k, t_k)$

SOLUTION: A graph $T = (V_T, E_T)$ in G such that each set of source/destination pairs is strongly connected.

COST FUNCTION: The sum of the costs of the edges in T, and the sum of the edge costs of each minimal cost path between each source/destination pair. $\sum_{e \in E_T} c(e) + \sum_{e \in P_k} c(e)$ for each minimal cost path P_k between s_k, t_k.

OBJECTIVE: Minimize

Approx: ?

Hardness: ?

- Cable/Tray Costs: 1:1
- Tray Fill Rate: don't handle
- Existing Tray: no existing tray
- Voltage Categories: no voltage categories
- Online Arrival of Cables: offline
- Dynamic Environment: static
- Jumper Cost: no penalty
- Height: no penalty
- Turn Cost: no penalty

2.1.3 Cable Support Tradeoff Problem

INSTANCE: Graph $G = (V, E)$, edge distance $d : E \to [0, \infty]$, tray cost $t \in [0, \infty]$, cable cost $c \in [0, \infty]$. A set of source/destination pairs $S = (s_1, t_1), ...(s_k, t_k)$.

SOLUTION: A graph $T = (V_T, E_T)$ in G such that each set of source/destination pairs (s_k, t_k) is strongly connected.

COST FUNCTION:

The sum of the tray cost of each edge in T, plus the sum of the costs of each minimal cable cost path P_k.

$t \cdot \sum_{e \in E_T} d(e) + c \cdot \sum_{n=0}^{n=k} \sum_{e \in P_n} d(e)$.

OBJECTIVE: Minimize

Approx: ?

Hardness: NP-hard to approximate within an approximation ratio 96/95 when $t = 0$. (at least as hard as a Steiner forest, potentially worse than this in other cases)

Comment: When $t = 0$, this problem simplifies to the **shortest path problem**. When $c = 0$ this simplifies to the **minimal Steiner forest problem**.

- Cable/Tray Costs: tradeoff
- Tray Fill Rate: don't handle
- Existing Tray: no existing tray
- Voltage Categories: no voltage categories
- Online Arrival of Cables: offline
- Dynamic Environment: static
- Jumper Cost: no penalty
- Height: no penalty
- Turn Cost: no penalty

2.1.4 Cable Support Problem Variant: [Existing Tray, Independent voltage categories, Material dependent routing cost, Linear jumper penalty] - Currently deployed as of Jan 2026

INSTANCE: Graph $G = (V, E)$, edge costs $c : E \rightarrow \mathbb{R}^+$, set of source/destination pairs $S = (s_1, t_1), ...(s_k, t_k)$. Edge costs $c(e)$ are assigned by multiplying the geometric distance of the edge with a scalar for each type of edge (ie. Steel:= dist*0.5, Jumper := dist*2, Tray := dist*0.1). A set of k voltage categories Z, one for each source/destination pair.

SOLUTION: A set of k paths P, $P_k = (s_k, ..., t_k)$.

COST FUNCTION: The sum of the costs of each path. $\sum_{n=0}^{n=k} \sum_{e \in P_n} c(e)$.

OBJECTIVE: Minimize

Hardness: Has the hardness P, due to existence of near linear algorithms including $O((E+V)logV)$ - Heap implemented Dijkstra [1]. This for a polynomial number of cables will therefore be polynomial in complexity.

Comment: This is reducible to the **shortest path problem**, as it only has a specified edge cost function. As of Jan 2026, there is a solution to this based on independent Dijkstra. A post processing step is performed to identify non-support edges run along and those are assigned as tray, the number of voltage categories in the edge representing the number of trays to place per edge.

- Cable/Tray Costs: material specific cable costs (encoded in c(e) function)
- Tray Fill Rate: don't handle
- Existing Tray: existing tray (encoded in c(e) function)
- Voltage Categories: independent voltage categories
- Online Arrival of Cables: offline
- Dynamic Environment: static
- Jumper Cost: linear penalty (encoded in c(e) function)
- Height: no penalty
- Turn Cost: no penalty

2.2 Cable Routing Problems

Other related routing problems that have not yet been documented.

2.2.1 Engineered Routing Problem

References

[1] Michael L Fredman and Robert Endre Tarjan. "Fibonacci heaps and their uses in improved network optimization algorithms". In: Journal of the ACM (JACM) 34.3 (1987), pp. 596–615.

[2] Mathias Hauptmann and Marek Karpinski. A compendium on Steiner tree problems. Inst. für Informatik, 2013. URL: https://theory.cs.uni-bonn.de/info5/steinerkompendium/netcompendium.pdf.