Creating synthetic distribution networks

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I Algorithm

Let H denote the set of activity locations (e.g., homes, work locations). Let $R = (V_R, E_R)$ be a graph representation of the road network, where V_R denotes its set of nodes (e.g., intersections, places where road structure changes), and where E_R denotes its edges (also referred to as links.) Each link has associated an integer level from the set $\{1, 2, 3, 4, 5\}$ that describes the link type (e.g., a level-1 link could correspond to an Interstate road segment, while a level-5 link could correspond to a residential road.) Let S denote the set of substations. The algorithm steps can be listed as follows: (*i*) From the set of links E_R, remove all links with level ≤ 2. These links are dropped since components of the distribution network (e.g., homes) are typically not located along these links.

A Map substation to road network nodes:

(*ii*) Construct a mapping $g : S \to V_R$ assigning to each substation $s \in S$ its closest (least *great circle distance*) road node $g(s) \in V_R$. Let N denote the set of all road nodes $g(s)$.

$$N = \{g(s), s \in S\}$$

Thus, the set N denotes the set of road network nodes which are closest to the substations.
(*iii*) Calculate the network distance between points (v, n) where $v \in V_R$ and $n \in N$ and construct a mapping $q : V_R \to N$ assigning to each node $v \in V_R$ its closest (least distance in the network) road node $q(v) \in N$. Therefore, it indirectly maps each point in the road network to the substations.

B Constructing primary distribution network:

(*iv*) For substation s, the induced subgraph of R given by $K_s = \{V_{Ks}, E_{Ks}\}$ is chosen where

$$V_{Ks} = \{v \in V_R | q(v) = g(s)\}$$

Then, depth first search (DFS) is performed on K_s to generate DFS tree T by selecting the root node as $g(s)$. Let $\mathcal{F} = \{T_1, T_2, \cdots\}$ denote the resulting forest of DFS trees for all the substations.

C Map road network nodes to home/activity locations:

(*v*) Construct a mapping $f : H \rightarrow E_R$ assigning to each location $h \in H$ its closest link $f(h) \in E_R$ (smallest Euclidean distance between the point and link segment).
(*vi*) Let $d(h, r)$ denote the great circle distance between the home/activity location h and the rode node $r \in V_R$ of link $f(h)$. Construct a mapping $p : H \rightarrow V_R$ assigning to each location $h \in H$ the nearest road node $p(h)$ satisfying

$$p(h) = \underset{r \in \{r_i, r_j\}}{\arg\min} \quad d(h, r)$$
$$\text{s.to.} \quad (r_i, r_j) \equiv f(h)$$

For each node $v \in V_R$, let $A(v)$ denote the set of locations mapped to v. This creates a mapping between the road nodes and the home/activity locations.

D Constructing secondary distribution network:

(*vii*) Let $M = \{h_1, h_2, \cdots, h_m\}$ be m home/activity locations mapped to road network node v. Find set of line segments $L = \{L_1, L_2, \cdots, L_n\}$ connecting the points in M such that
(*a.*) The line segments in L are non-intersecting.
(*b.*) The line segment L_k does not connect more than μ points of M.

II Results

Step 1: Map substation to the nearest road network node: The first step involves mapping the substations to the road network nodes. The great circle distance (distance on the earth's surface calculated from longitude-latitude) of all the road network nodes from each substation are calculated. The substations are mapped to the nearest road network node. Fig. 1 shows the mapping for the town of Blacksburg. Here, the substations are denoted in black circles and the nearest road network nodes are identified by the colored dots. The road network is depicted in yellow color.
Step 2: Map substation to road network nodes: The next task is to map all the road network nodes to a suitable substation. The network distance between all the road network nodes is evaluated for this purpose. The nodes which have the minimum network distance to the substation nearby road network node are grouped and mapped to the substation. Fig. 2 shows the mapping for the substations and road network of the town of Blacksburg. The black dots represent the substations and the colored nodes indicate the grouped road network nodes having the minimum distance to the colored nodes evaluated in Fig. 1.
Step 3: Layout the primary distribution system: The primary distribution network connects the substation to the pole top transformers through high voltage lines (12-30kV). It is assumed that the primary distribution follows the transportation network to the maximum extent. The primary distribution has a radial/tree structure. For each substation, an induced graph is extracted as in Fig 2 and a radial graph is generated for each such induced graph. Fig. 3 shows the primary distribution network for the town of Blacksburg. The black dots represent the substations and the colored trees indicate the primary distribution network originating from each substation. The root node of each tree is denoted by a larger dot of the same color and these nodes are the ones which have been identified in Fig 1.
Step 4:Map the road network nodes to the homes: The home/activity locations are mapped to the road network nodes. First, the home/activity ceneters are mapped to the nearest link. Thereafter, the nearest road network node (out of the two nodes in the link) is identified for each home/activity location. Fig. 4 shows the primary distribution network along with the mapping between the road network nodes and the home/activity locations.

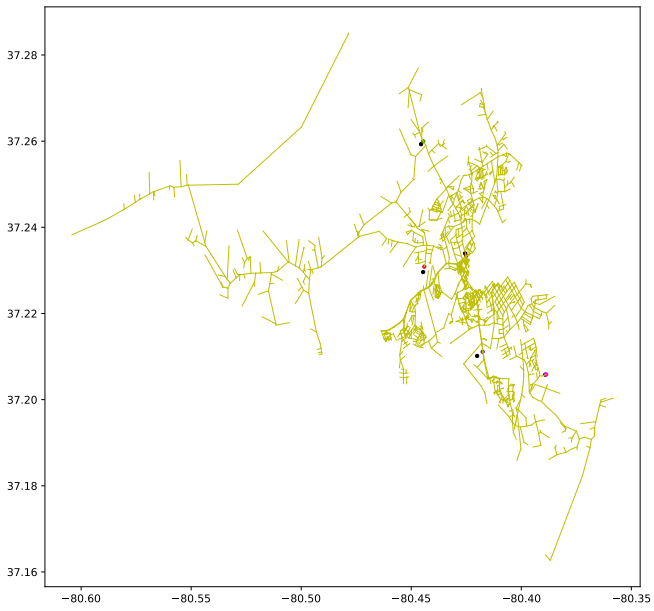

Figure 1: Substations of Blacksburg mapped to nearest road network node

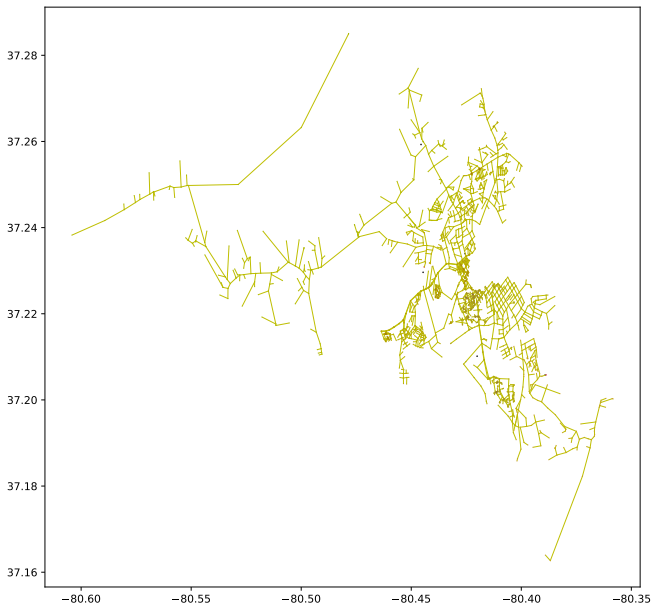

Figure 2: Substations of Blacksburg mapped to road network nodes

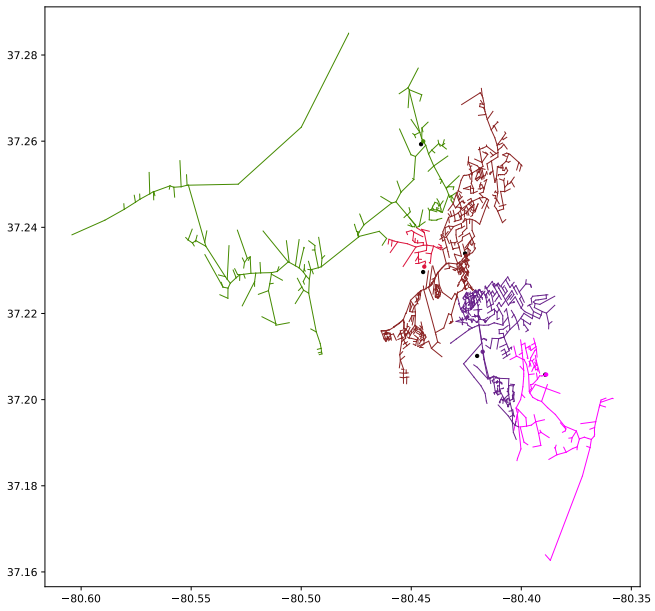

Figure 3: Primary distribution network from the substations in the town of Blacksburg

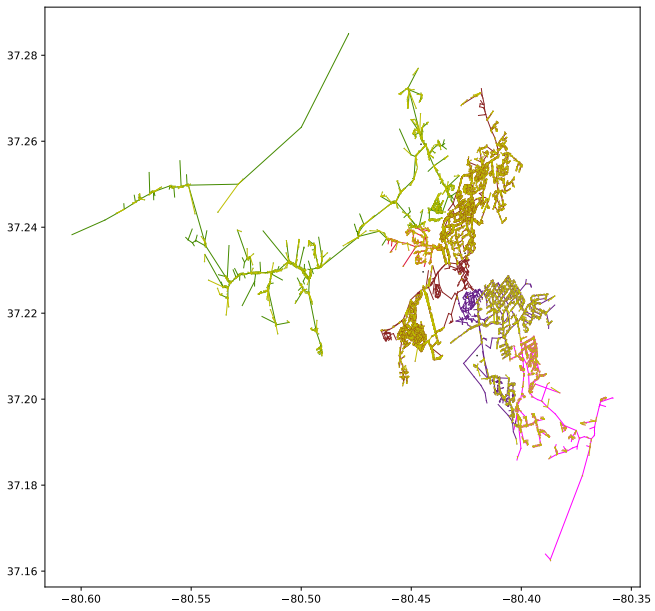

Figure 4: Road network nodes of Blacksburg mapped to the home/activity centers