Optimization of multiple UDWDM-PON based on physical restrictions and asymmetric users' clustering

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Outline

1. Introduction
2. Problem description
3. Employed Algorithms (heuristics)
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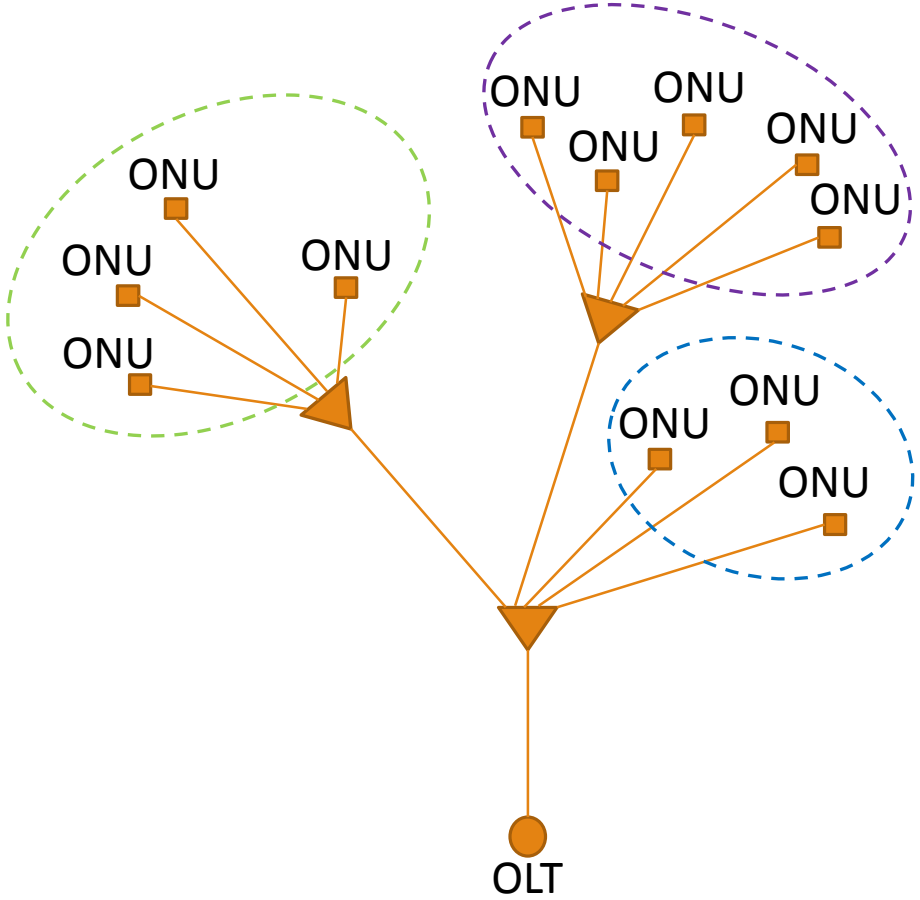
Introduction

The problem related with the optimal dimensioning of a PON can be approached in many different ways. The most cost-sensitive parameter for ODN design is the length of optical fiber and, in a lower grade of sensitiveness, the number of the distribution nodes.

The first step for finding the topology which minimizes the ODN deployment cost is choosing the proper way the users connect to the optical distribution network.



One of the facts related with the ODN deployment is the users' clustering and the way such clusters connect with each other and with the central office.

Problem description

Defining the following sets:

- The OLT: O={OLT},
- The set of ONU required for n users:
  U = {ONU1, ONU2,…, ONUn},
- The set of the available splitters:
  S = {S_k=Splitter$_k$1, Splitter$_k$2… / $k = 2^m$; m=1,…7}.
- The set of the candidate sites for placing splitters:
  V = {$v \in C$ / $C \equiv$ *set of clusters' center of mass*}.

Problem description

Defining the following variables:

- $x_{i,j}$ is equal to 1 if there is an optical link between points $(i,j) \in V$ otherwise it is equal to 0;
- $x^{l}_{i,j}$ is equal to 1 if the optical link between points (i,j) belongs to the path from OLT to the l^{th} ONU, otherwise it is equal to 0;
- $d_{i,j}$ defines the distance between two points *i* and *j*;
- s_i^k is equal to 1 if a splitter of capacity $k \in S$ is placed in the site $i \in V$.

Problem description

And considering the following constants:

- The fiber installation cost per unit length, C_{FO};
- The cost of a splitter with capacity k, C_k;
- The attenuation per unit length for the fiber: α
- The attenuation in a splitter: γ
- The PON power budget: L_{ODN}

Problem description

The search of optimal cost for WDM PON deployment may be formulated by the following optimization problem:

$$\min \quad C_{FO} \sum_{(i,j)\in E} x_{i,j} d_{i,j} + \sum_{k} \sum_{i\in V} C_k Y_i^k \qquad (1)$$

Subject to:

$$\sum_{j\in V} x_{i,j} = 1; \quad i \in O \qquad (2)$$

$$\sum_{j\in V} x_{i,j} = 1; \quad \forall i \in U \qquad (3)$$

$$\sum_{k\in K} s_i^k \leq 1; \quad \forall i \in V \qquad (4)$$

$$\sum_{j\in V} x_{i,j} > 1; \quad \forall i \in V \qquad (5)$$

$$\sum_{j\in V} x_{i,j} \leq k s_i^k; \quad \forall i \in V \qquad (6)$$

$$\sum_{(j,i)\in E} \alpha d_{i,j} x_{j,i}^l + \sum_{i\in V} \sum_{j\in V|(j,i)\in E} \gamma s_i^k x_{j,i}^l \leq L_{ODN}; \quad \forall l \in U \qquad (7)$$

NP-Hard problem

Algorithm description

CLUSTERING ALGORITHM BASED ON DELAUNAY'S TRIANGULATION:

Provided that the previously described problem is a NP-hard problem (it can not be resolved in polynomial time as the number of users increase), we had to employ heuristic approaches in order to find some feasible solutions.

We have found that a very effective way for clustering users is using a Voronoi's graph partition. That way the clusters' centers could be linked to each other employing a Delaunay triangulation, which corresponds to the dual graph of the Voronoi partition.

Provided that the Euclidian Minimum Spanning Tree (EMST) of the graph linking the clusters' centers is a subset of a Delaunay triangulation, through the use of heuristics it is possible to search the optimal Delaunay triangulation and its correspondent optimal EMST.

Algorithms description

Optimal topology search algorithm

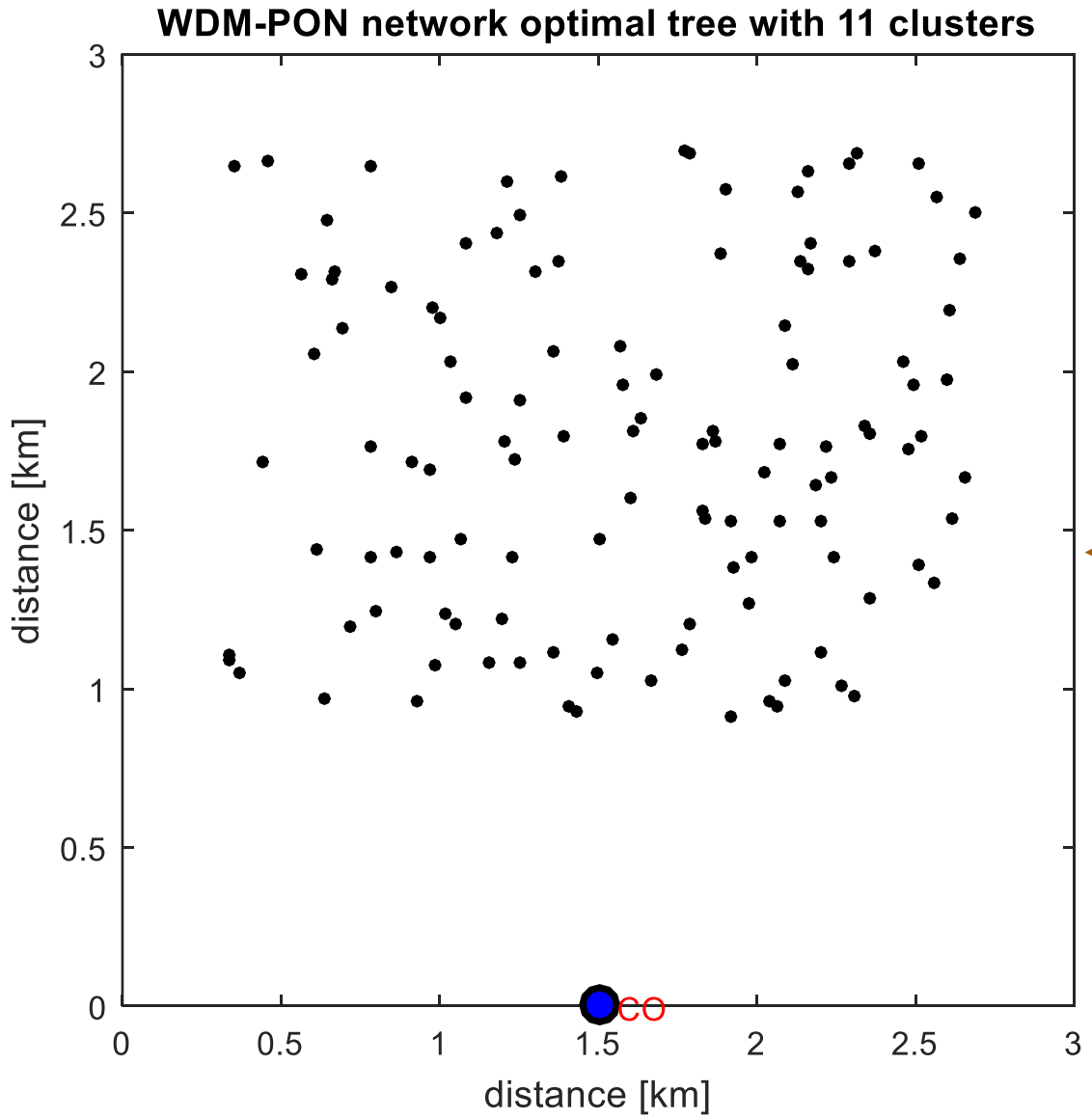
Step_1 $N = N_0$;

Step_2 for $i = N_0$:N do
Clusters = k-means(ONU, N);
Centers = center_of_mass(Clusters);
Link_candidates = Delaunay(Clusters, Centers);
Topology_i = Prim(Link_candidates);
Cost_Topology_i = Cost(Topology_i);
endfor;

Step_3 Best_cost = min(Cost_Topology_i);
Optimal_N = $i_{optimal}$;
Optimal_topology = Topology_ $i_{optimal}$;
Optimal_cost = Cost(Optimal_topology);

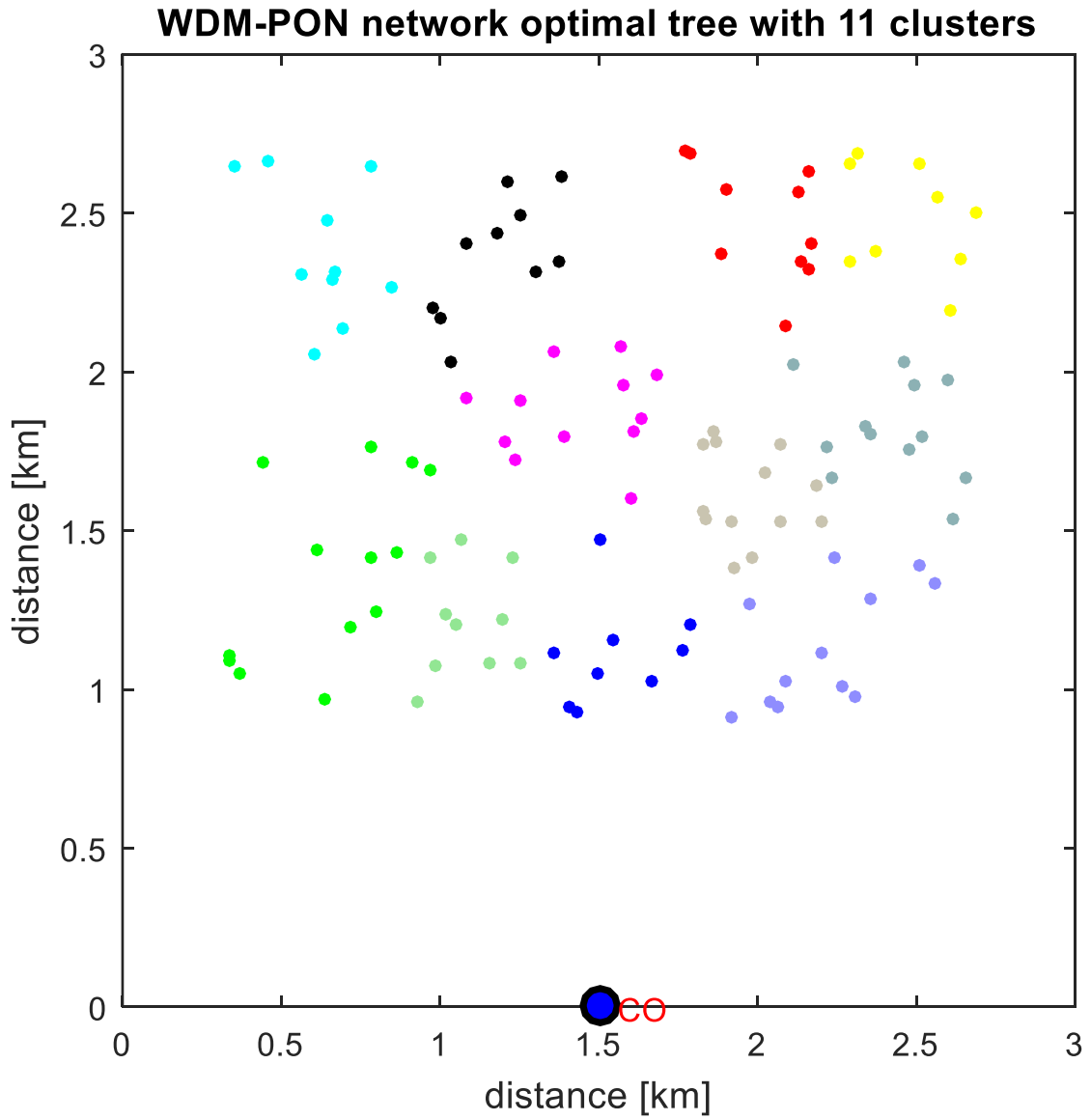
Step_5 return Clusters;

Algorithm description



Randomly placed users in a region with one central office (CO)

Algorithm description



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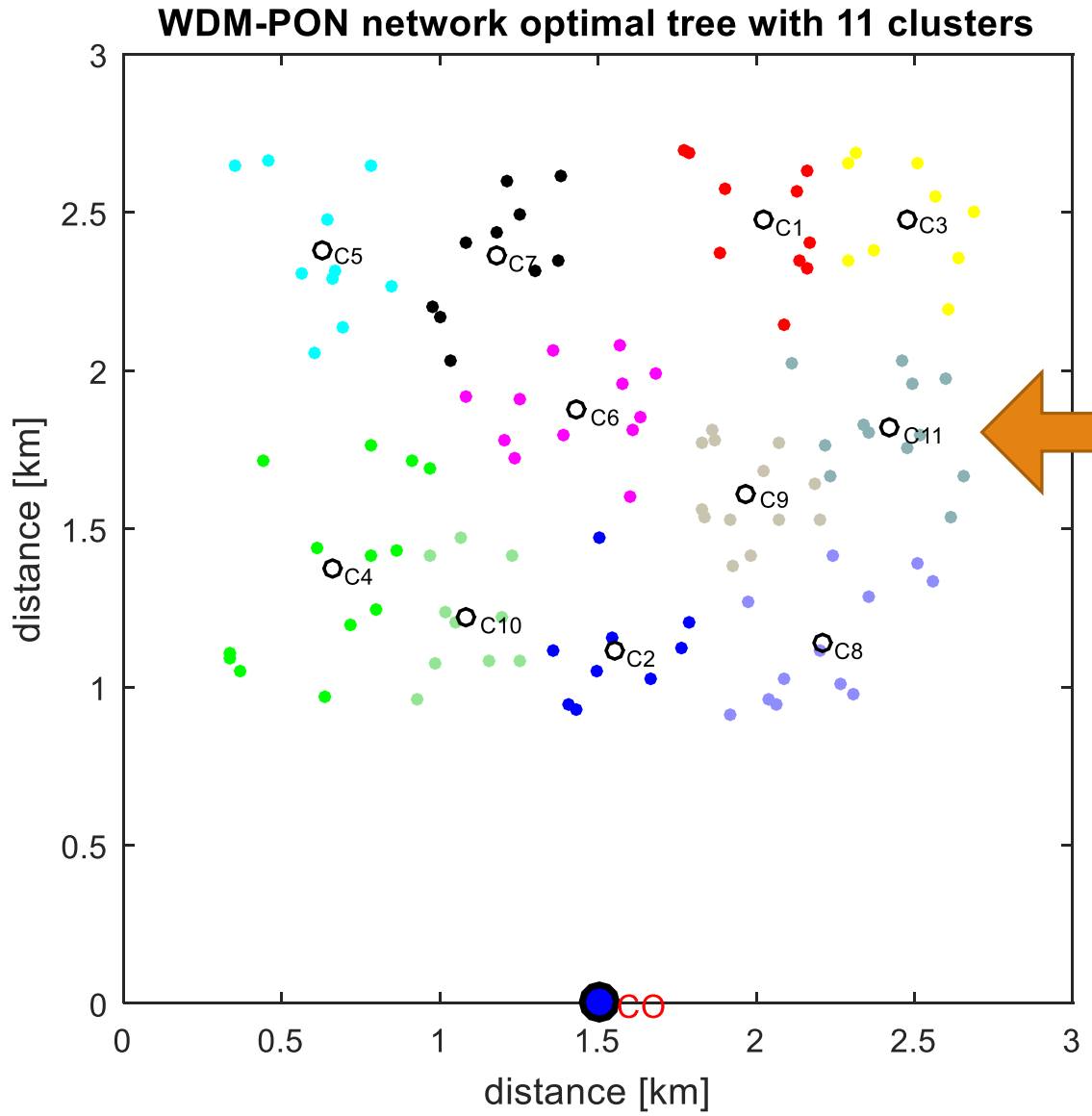
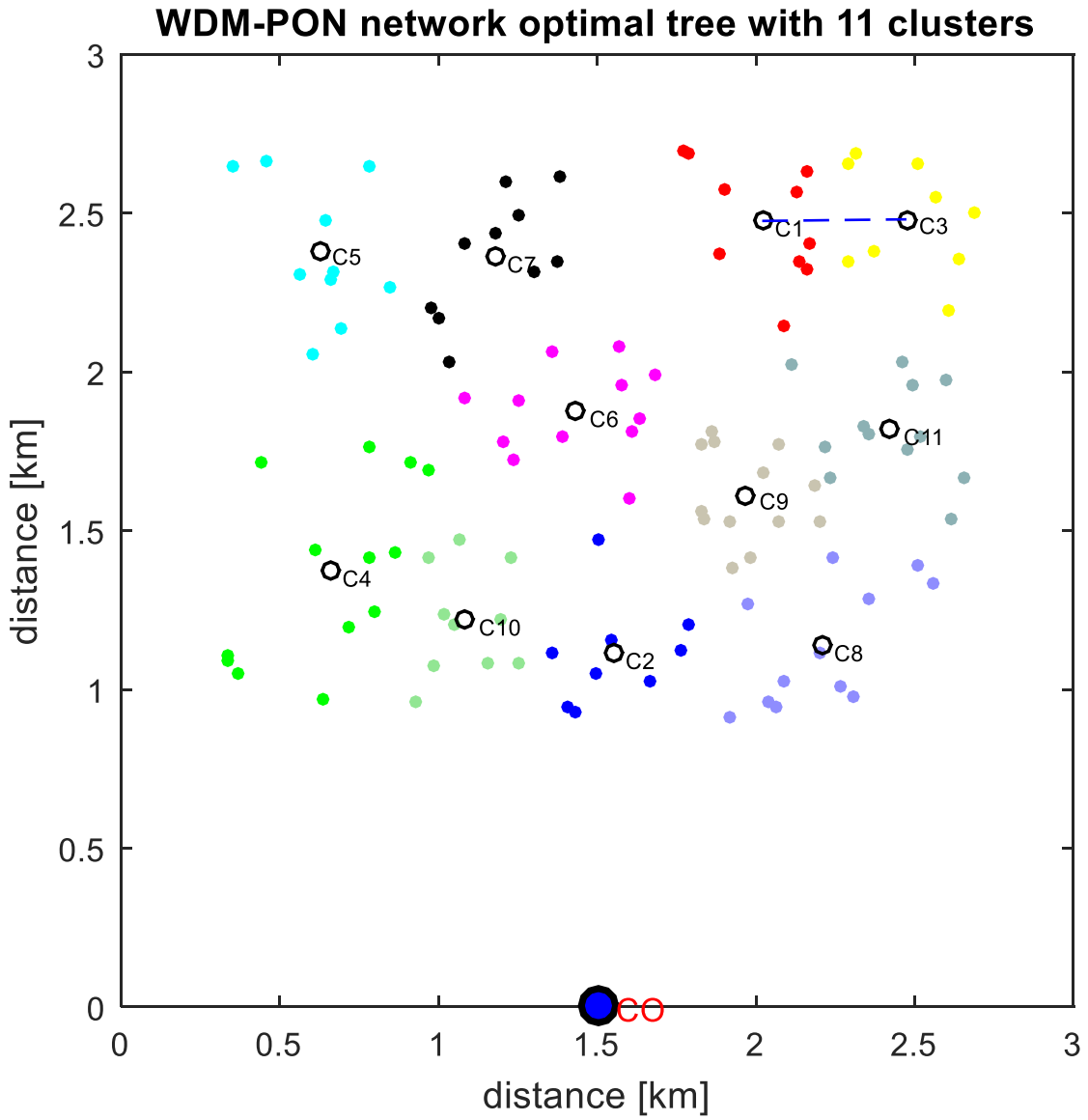


Modified K-means algorithm

Algorithm description



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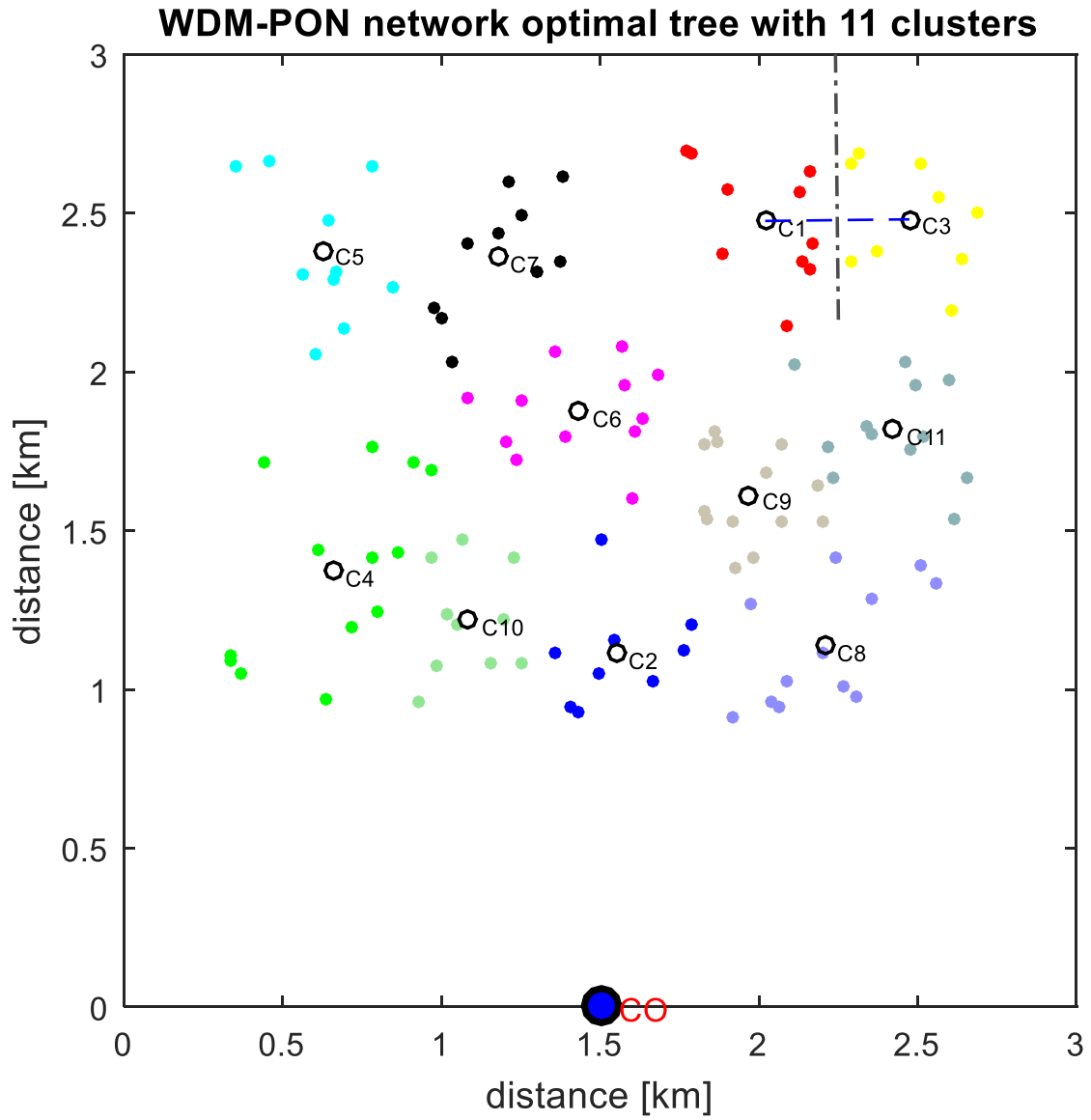

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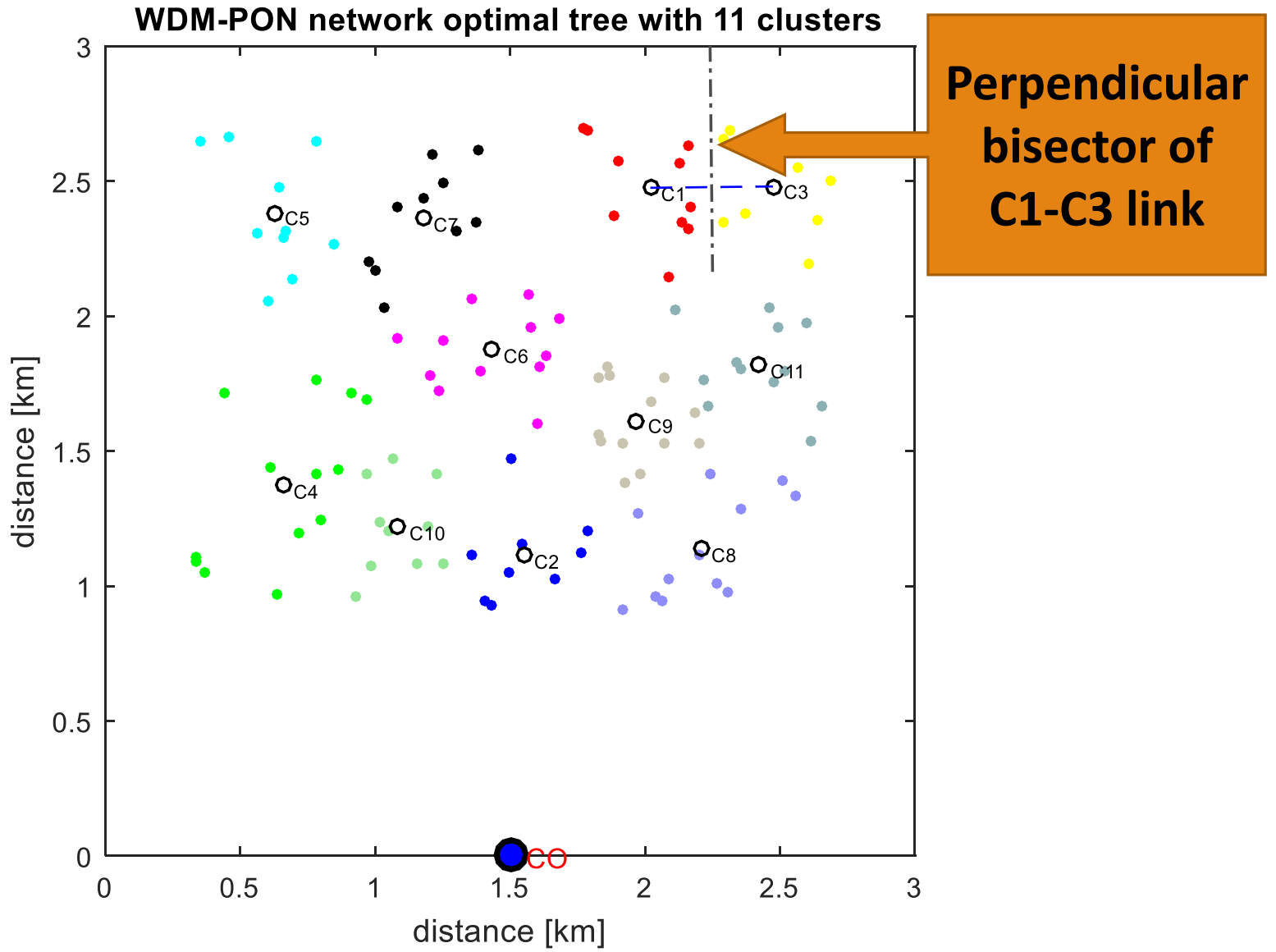
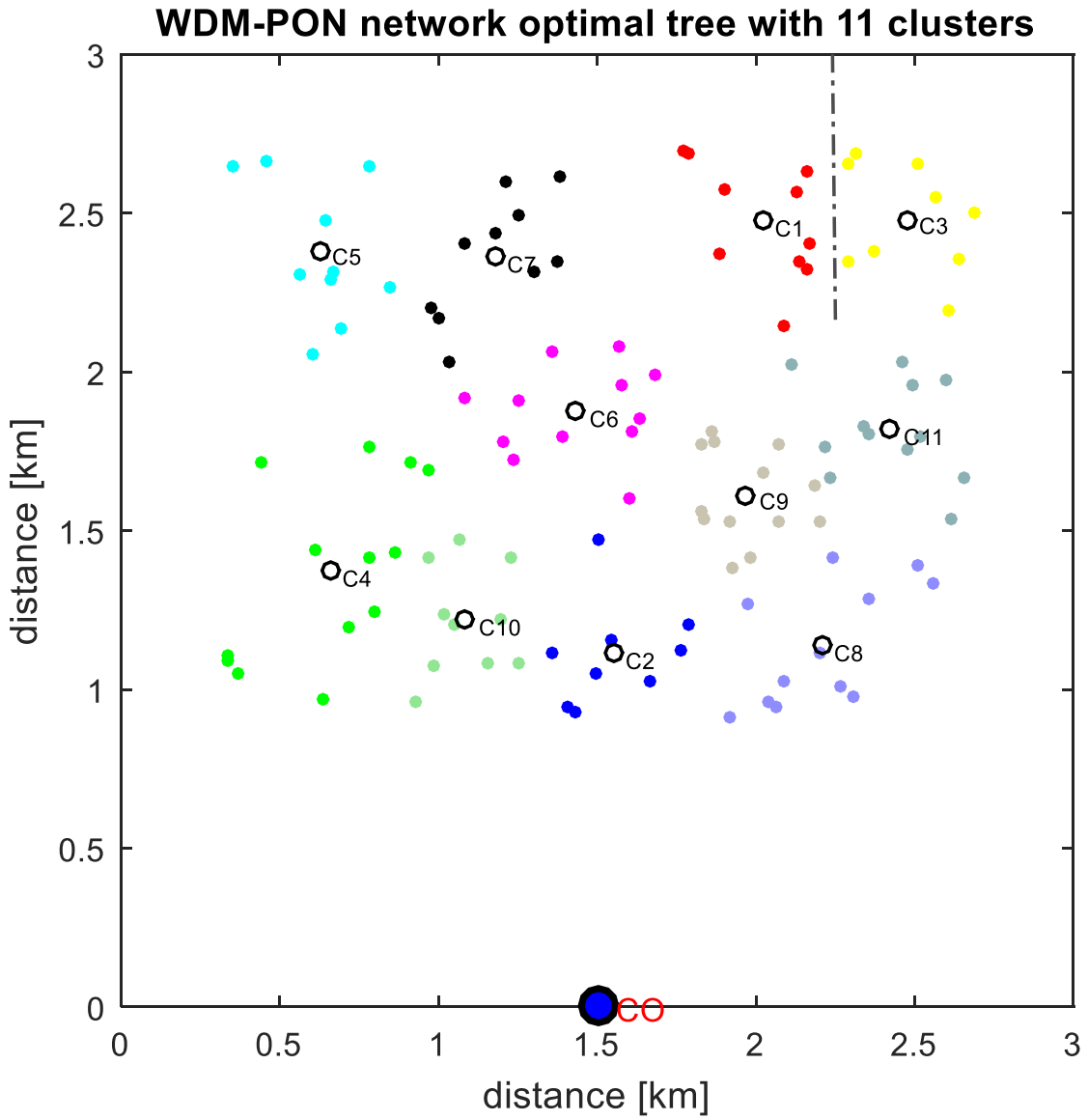


Perpendicular bisector of C1-C3 link

Algorithm description



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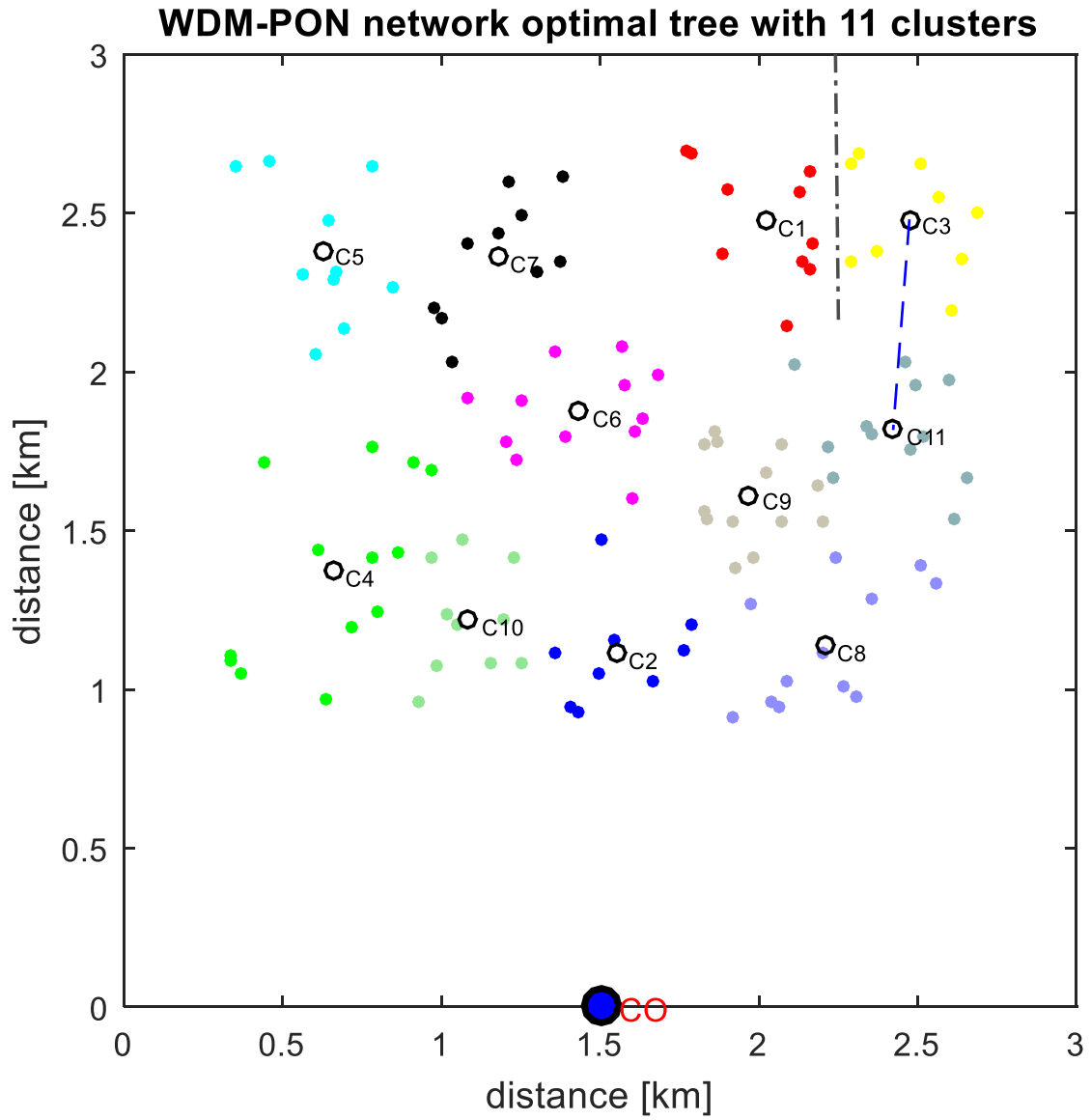

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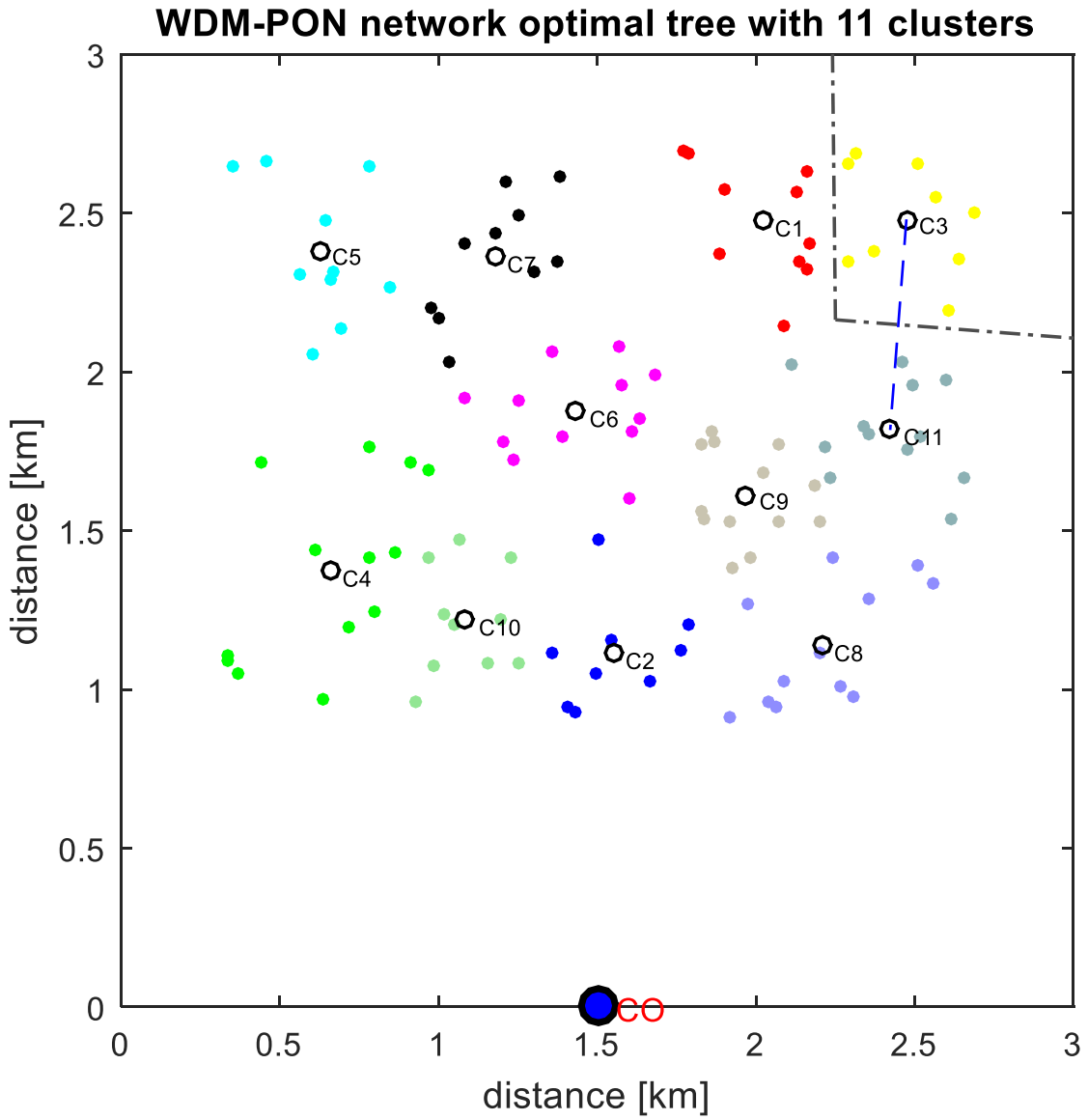

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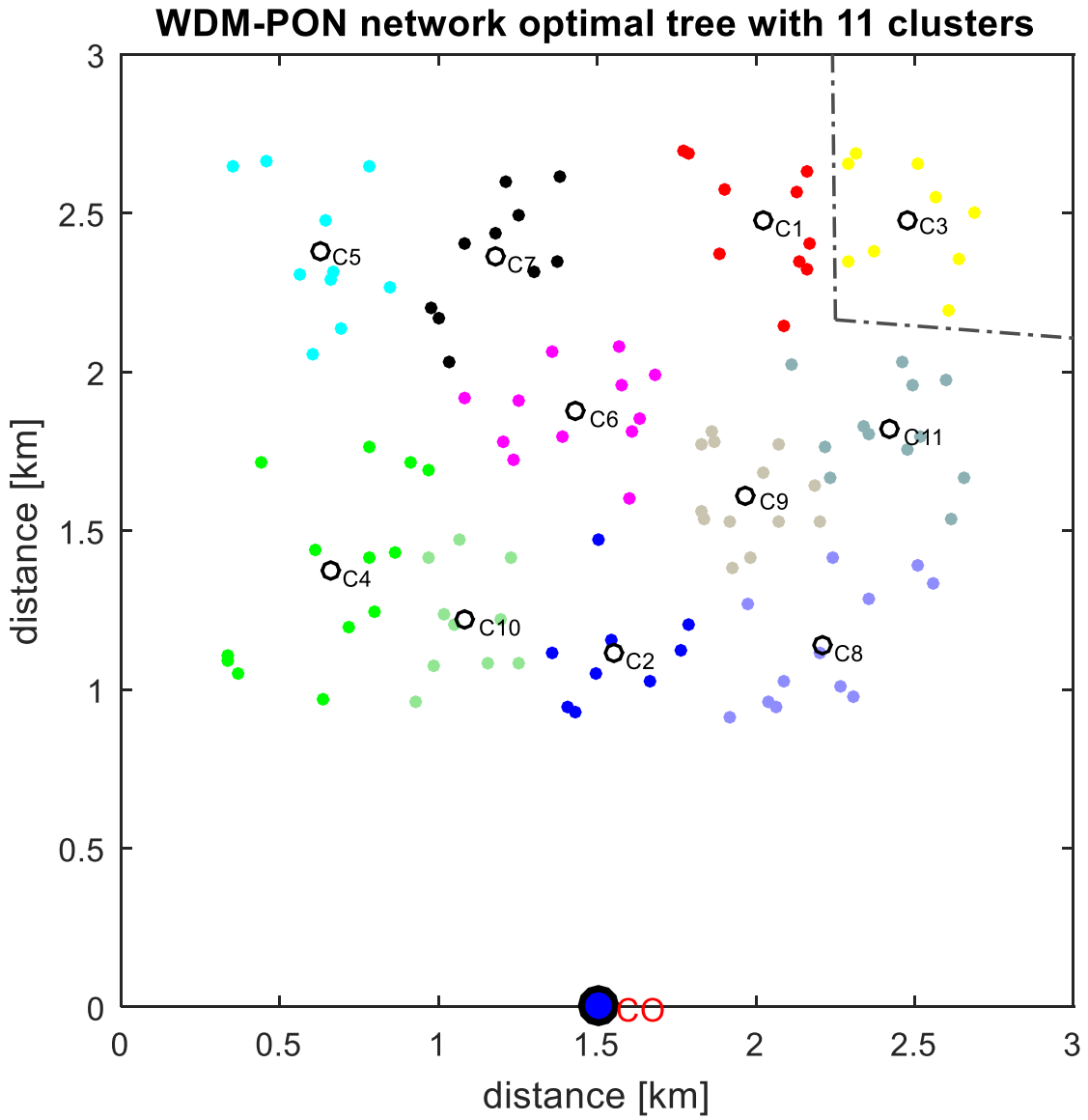

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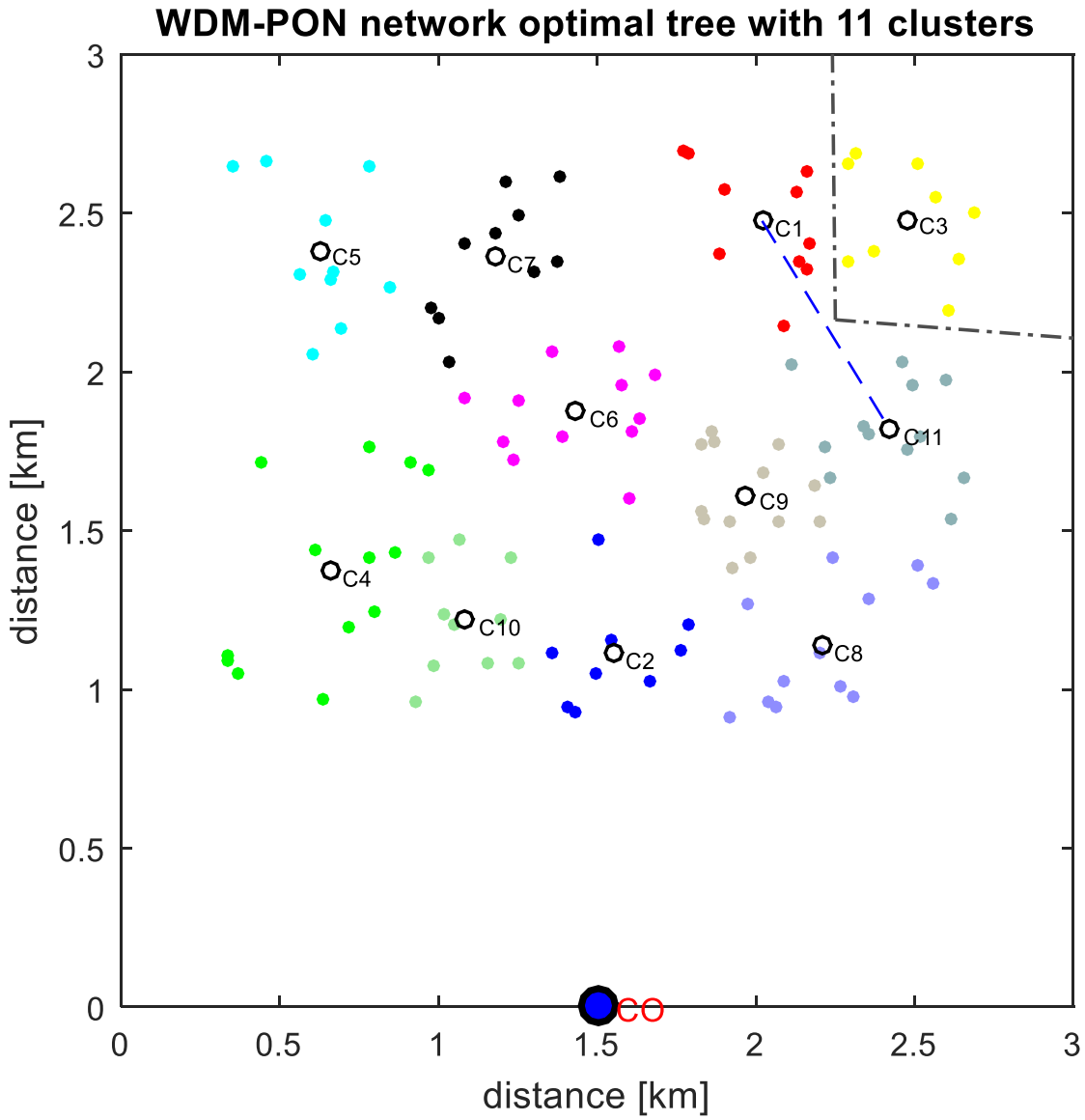

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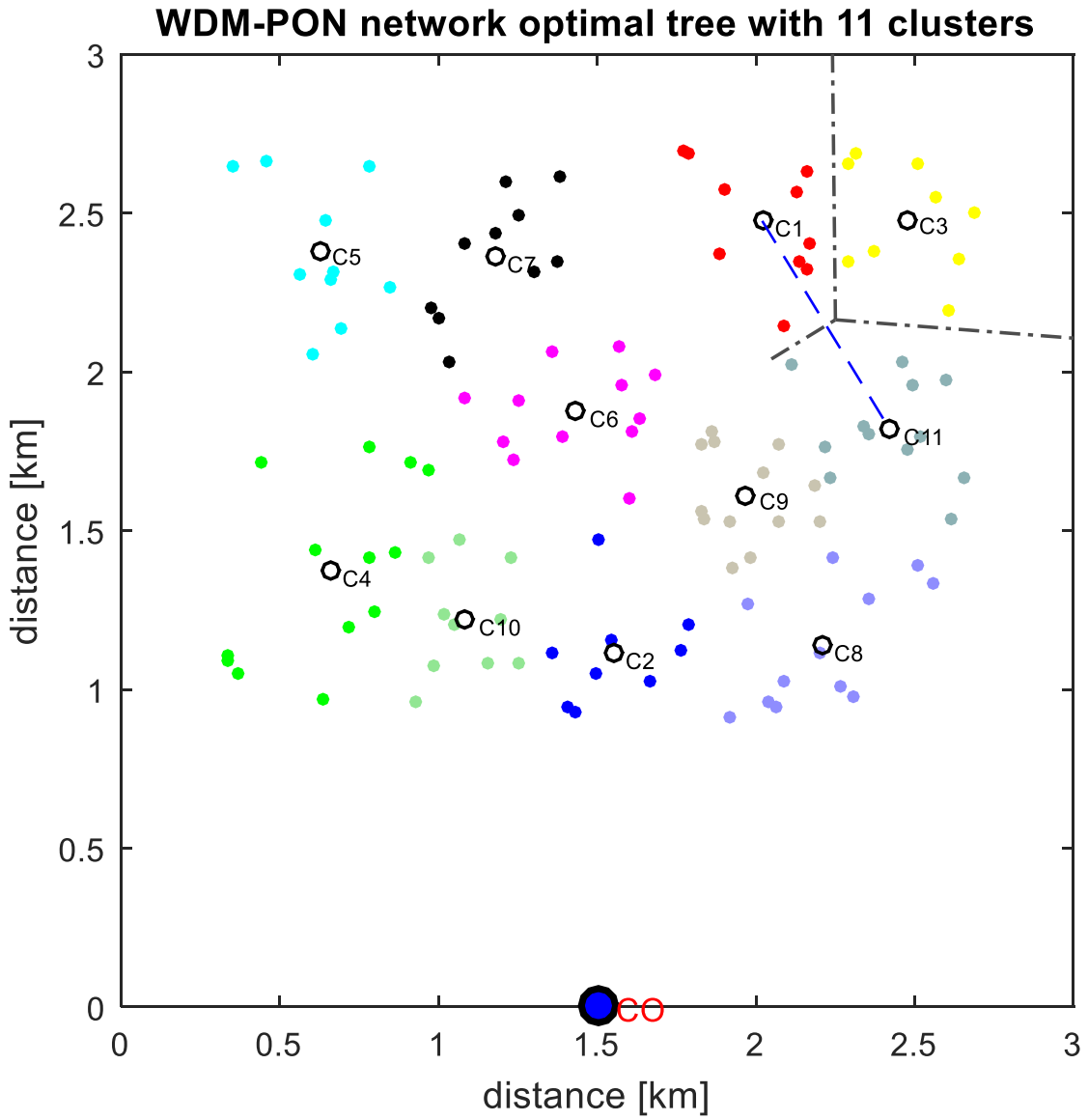

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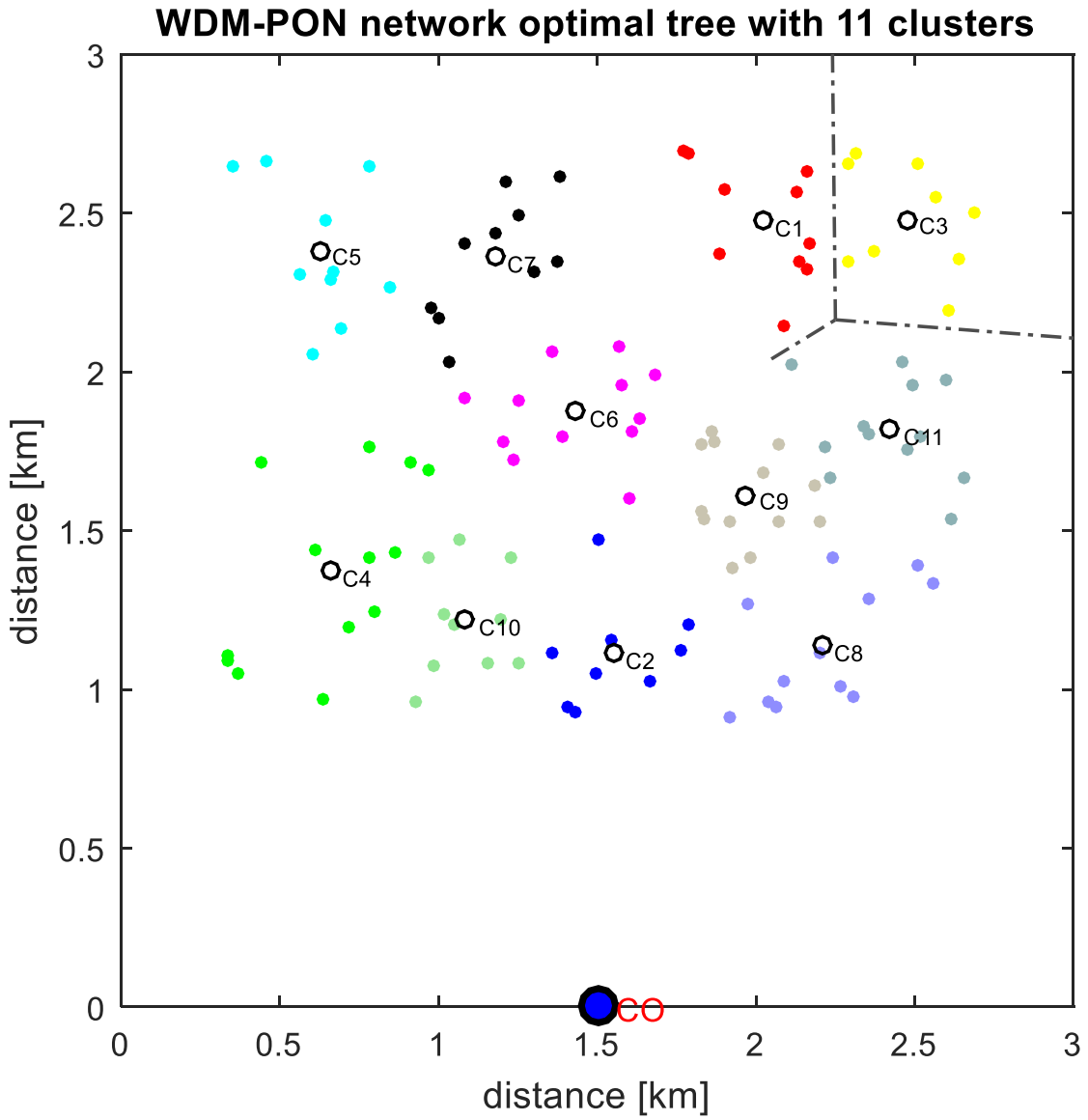

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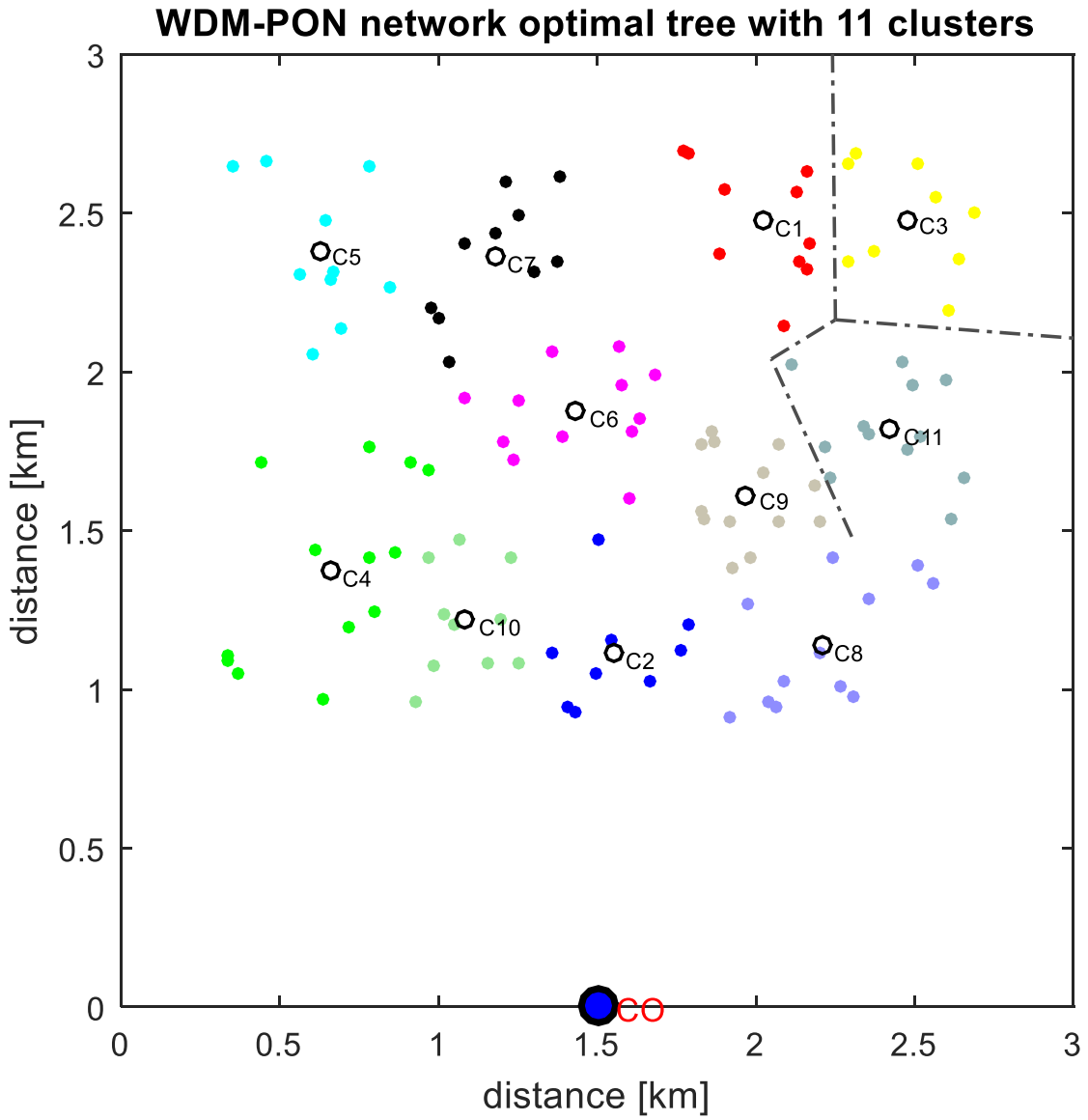

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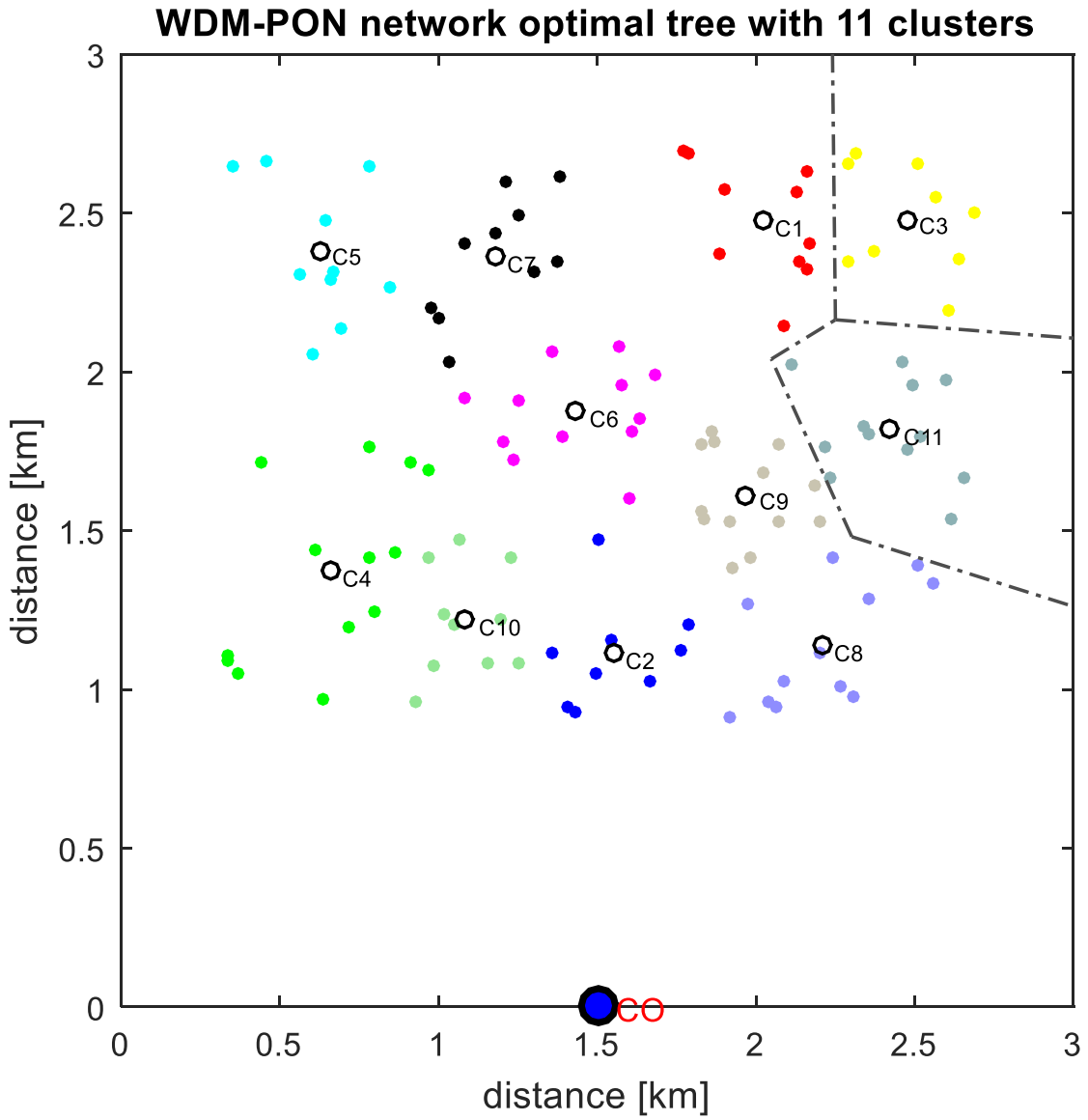

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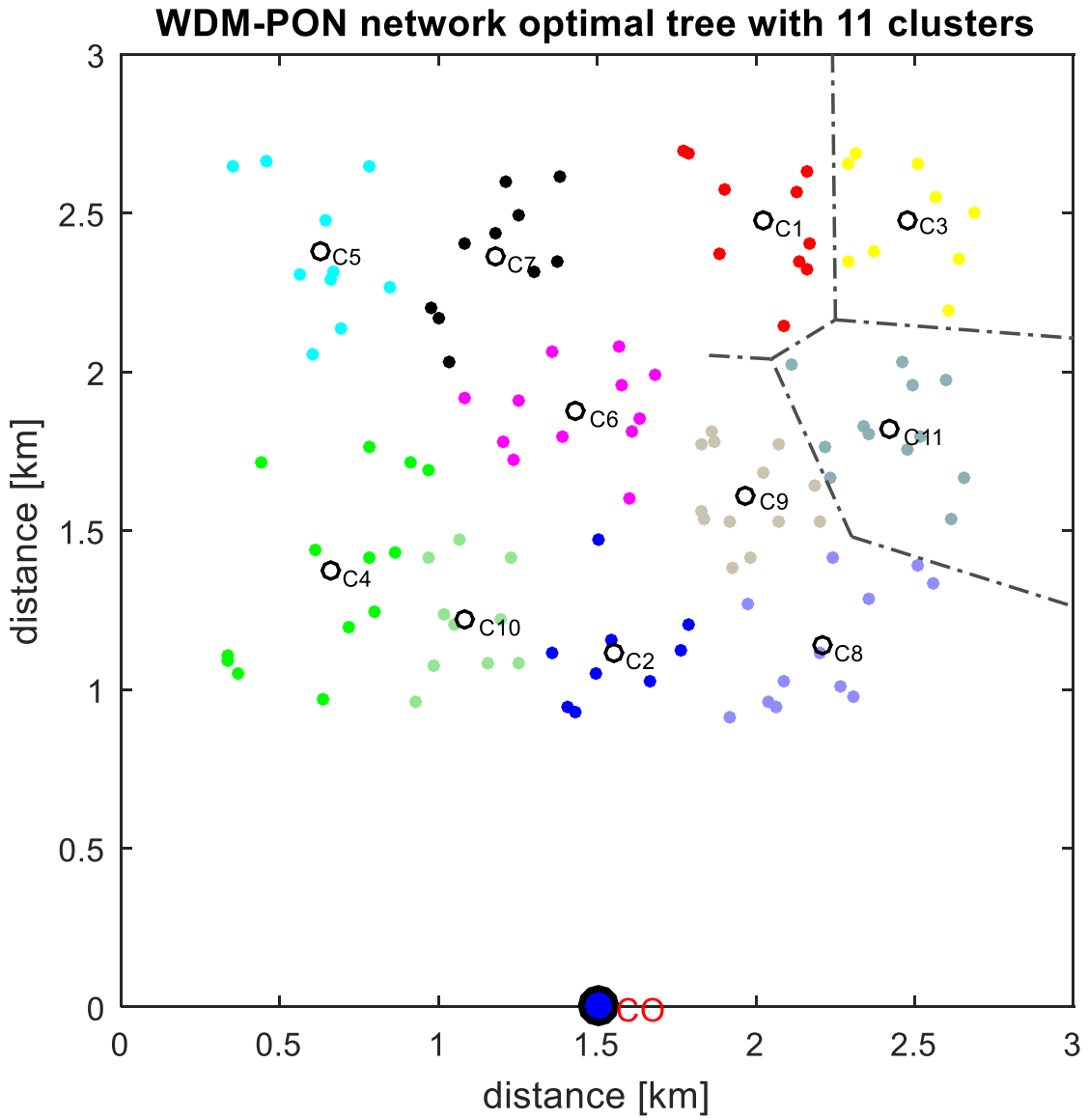

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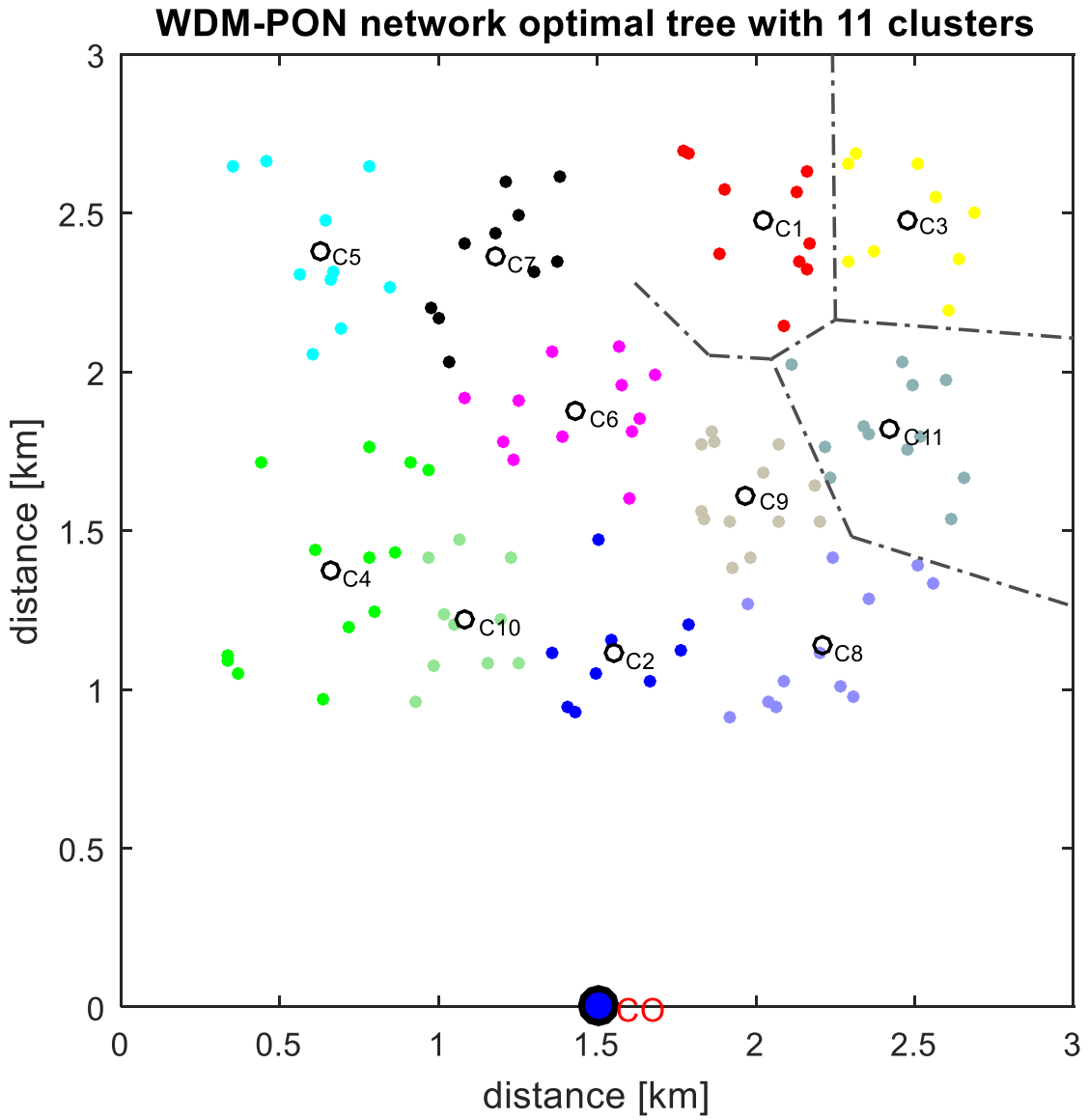

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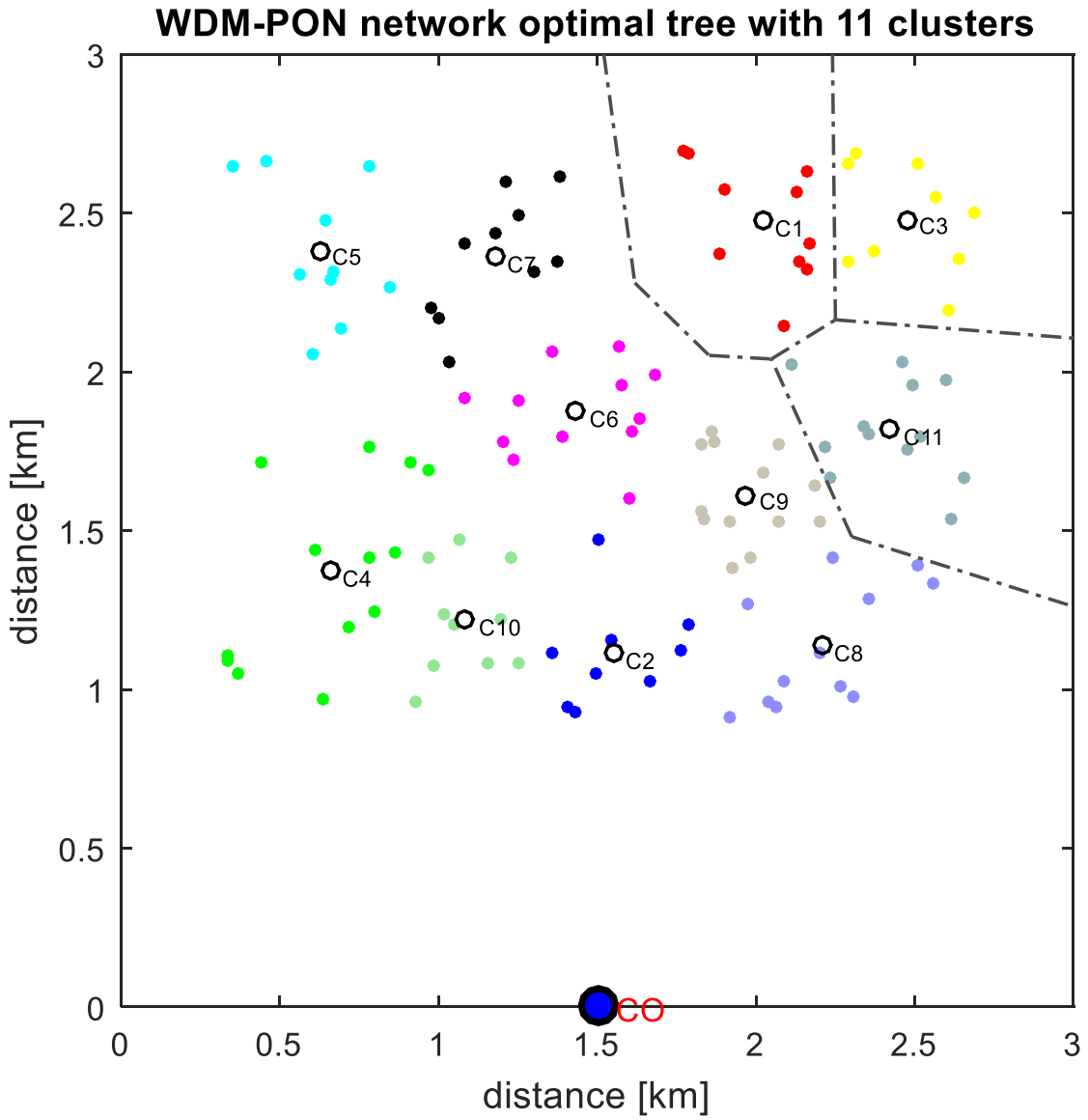

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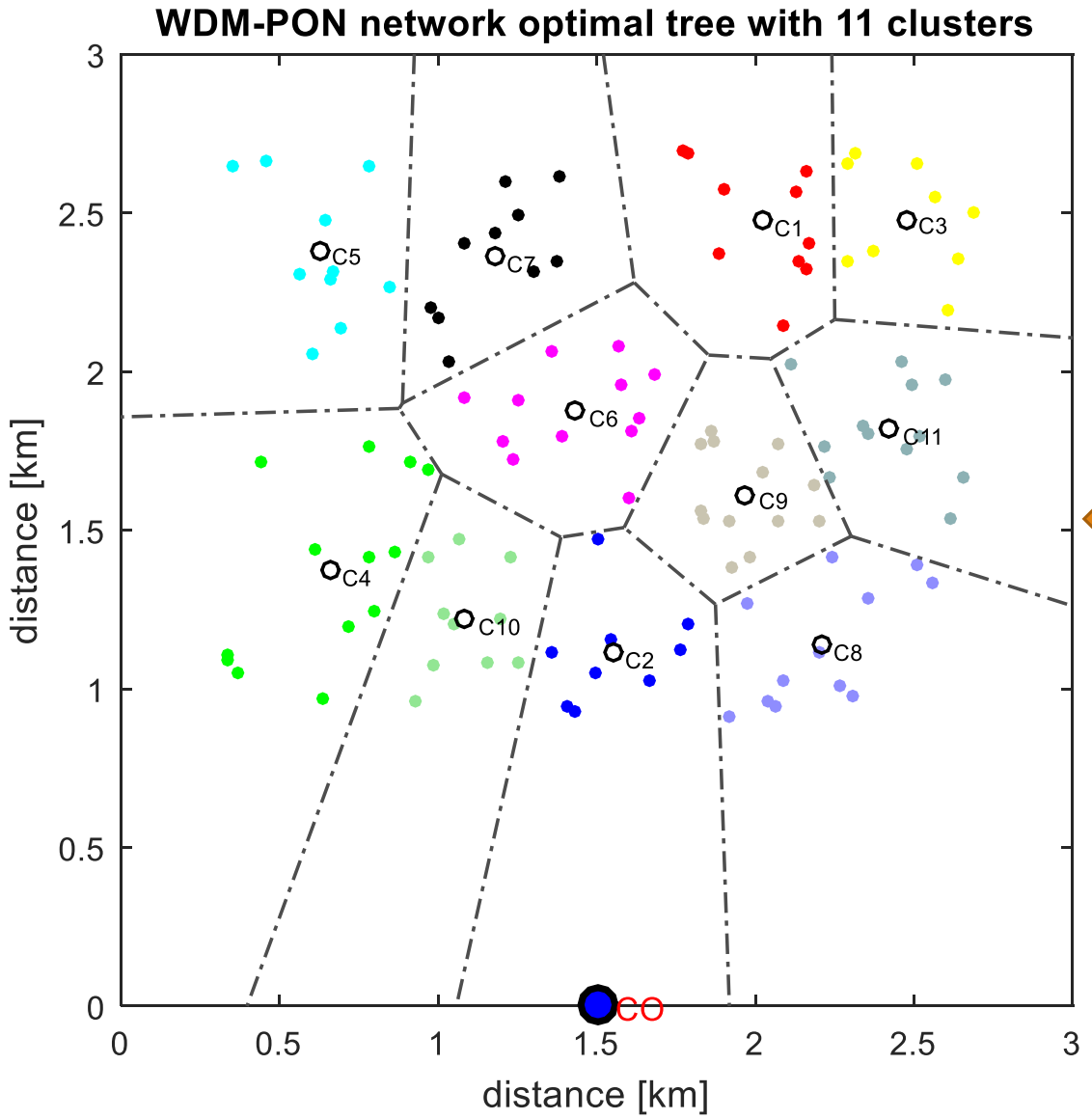
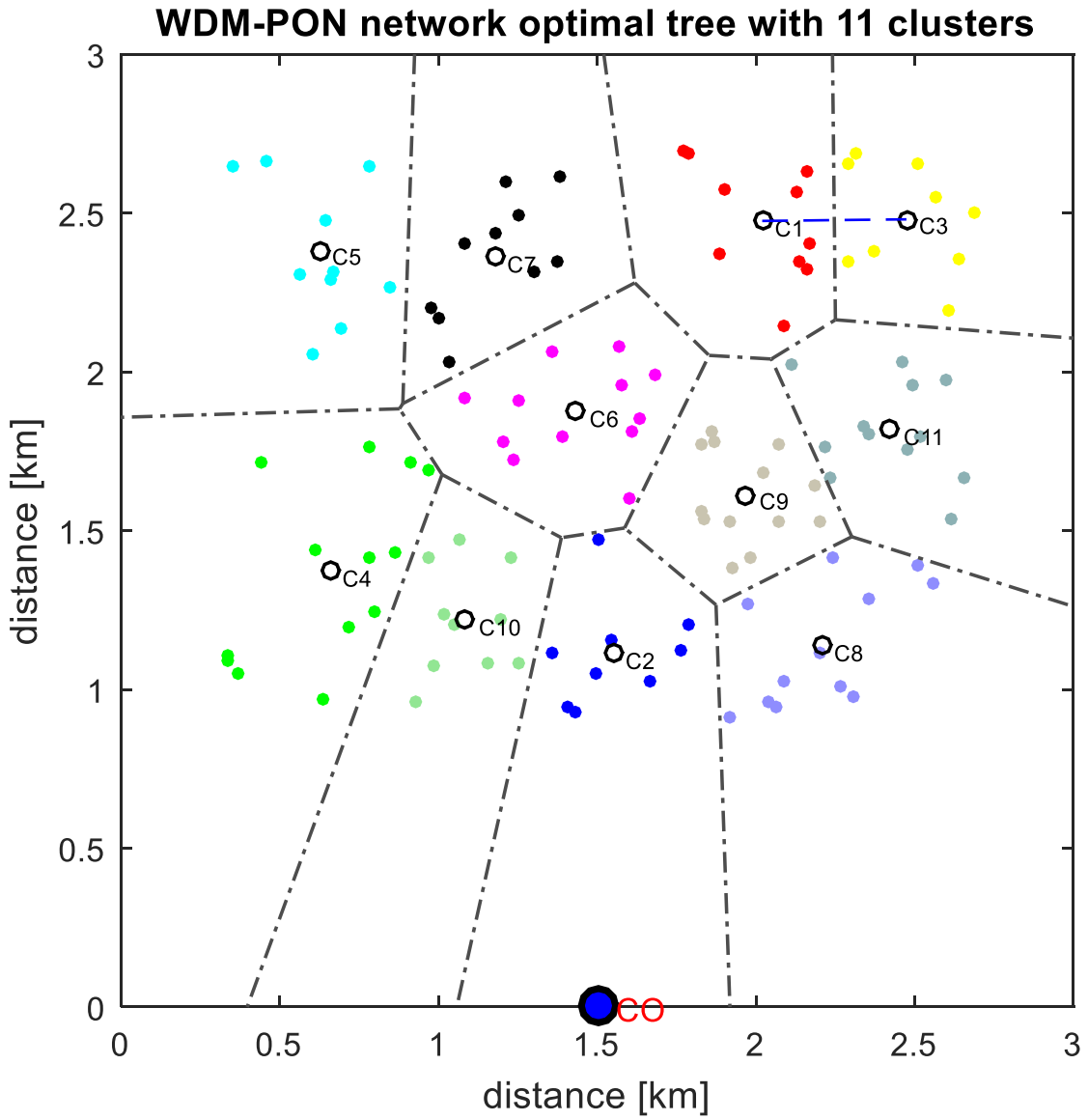


Voronoi's Tesellation

Algorithm description



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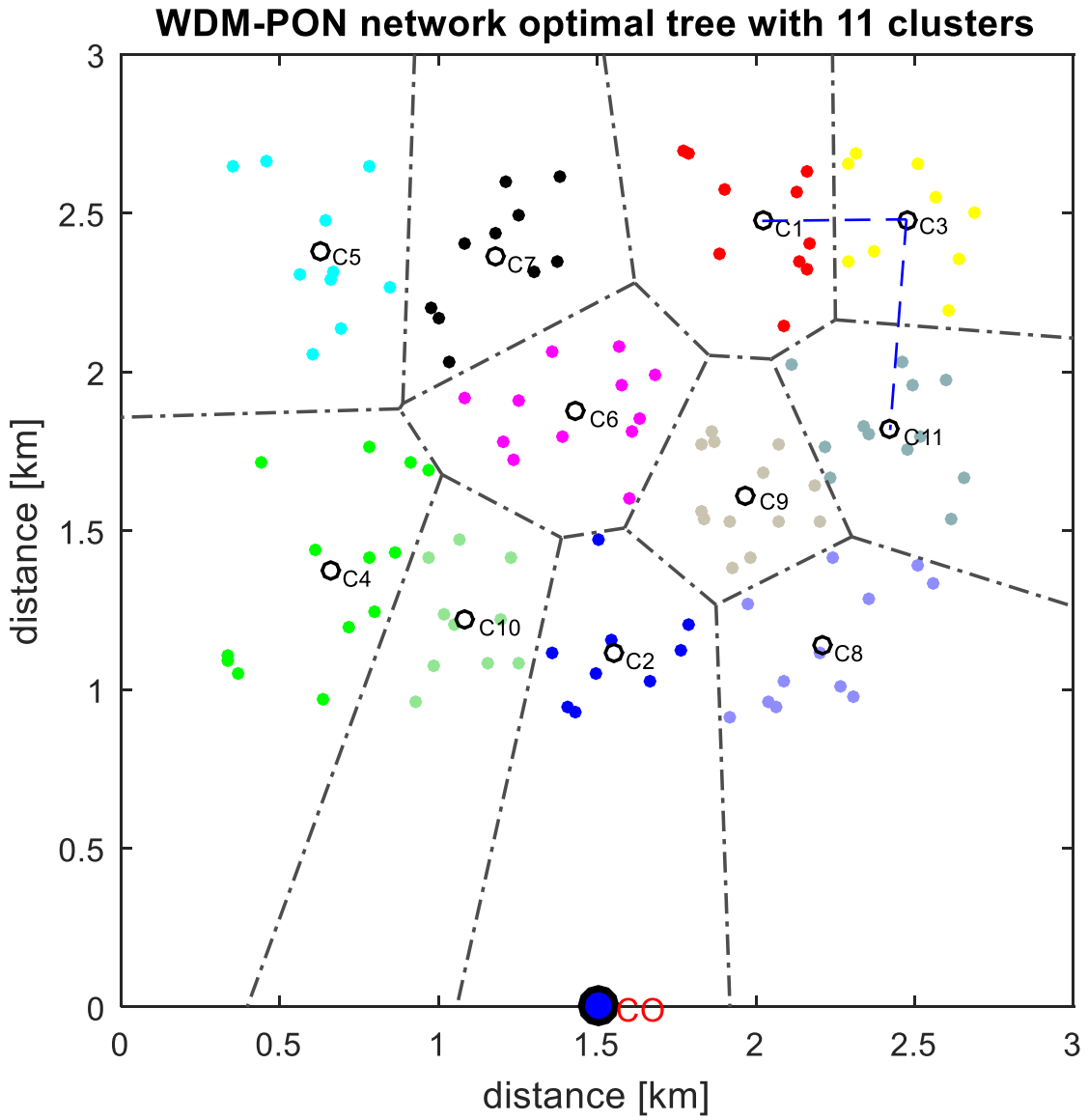

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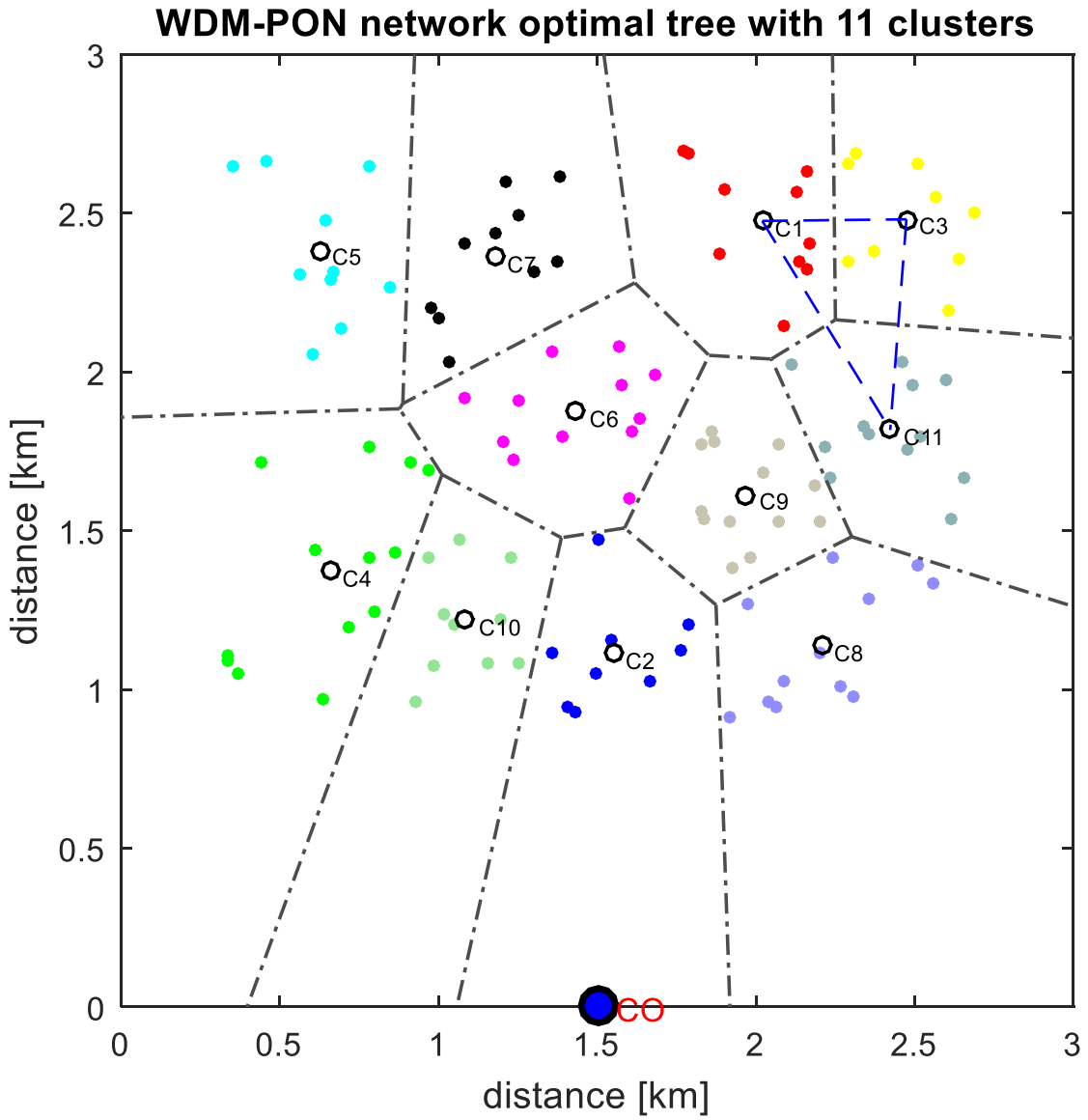

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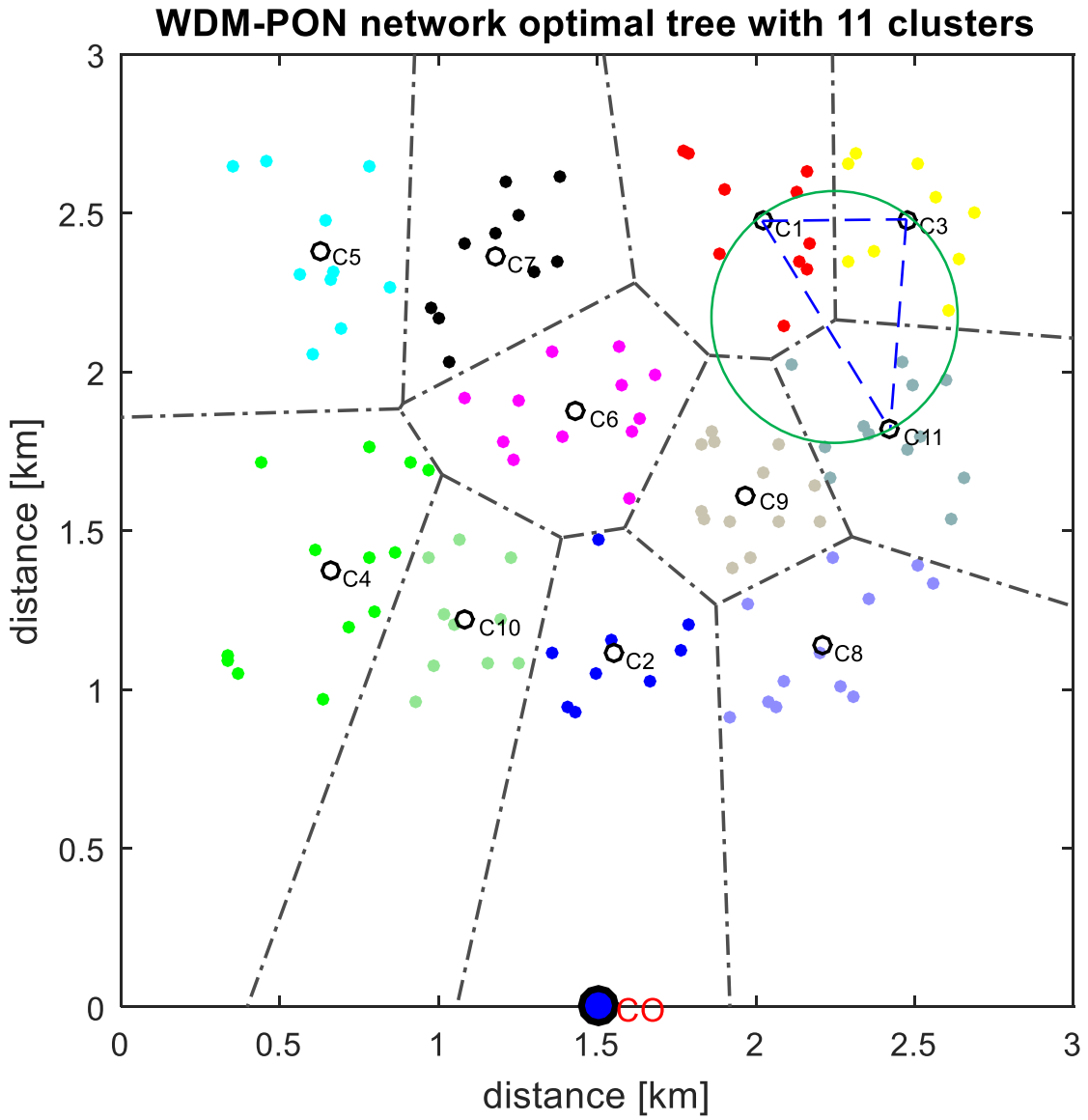

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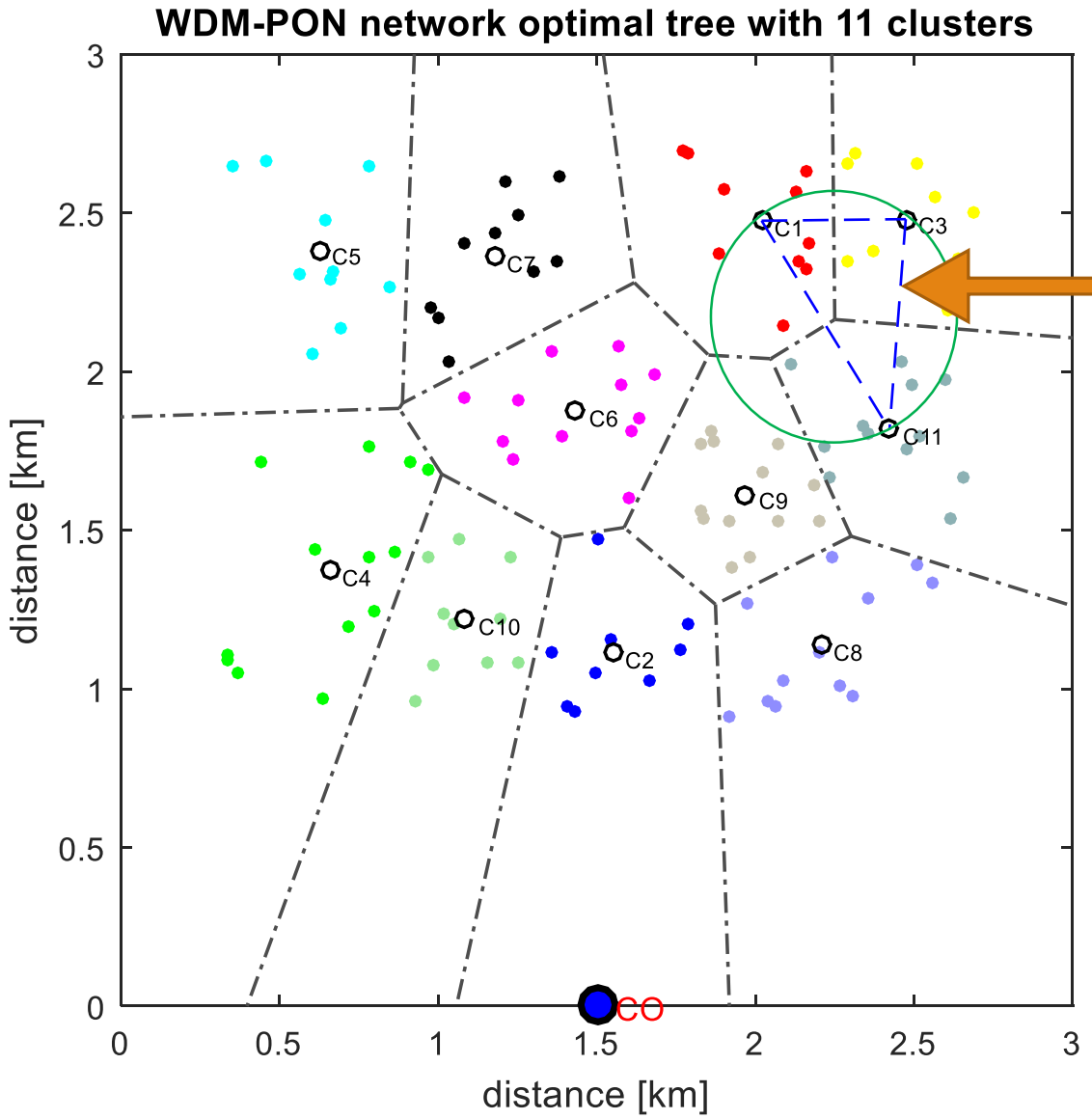
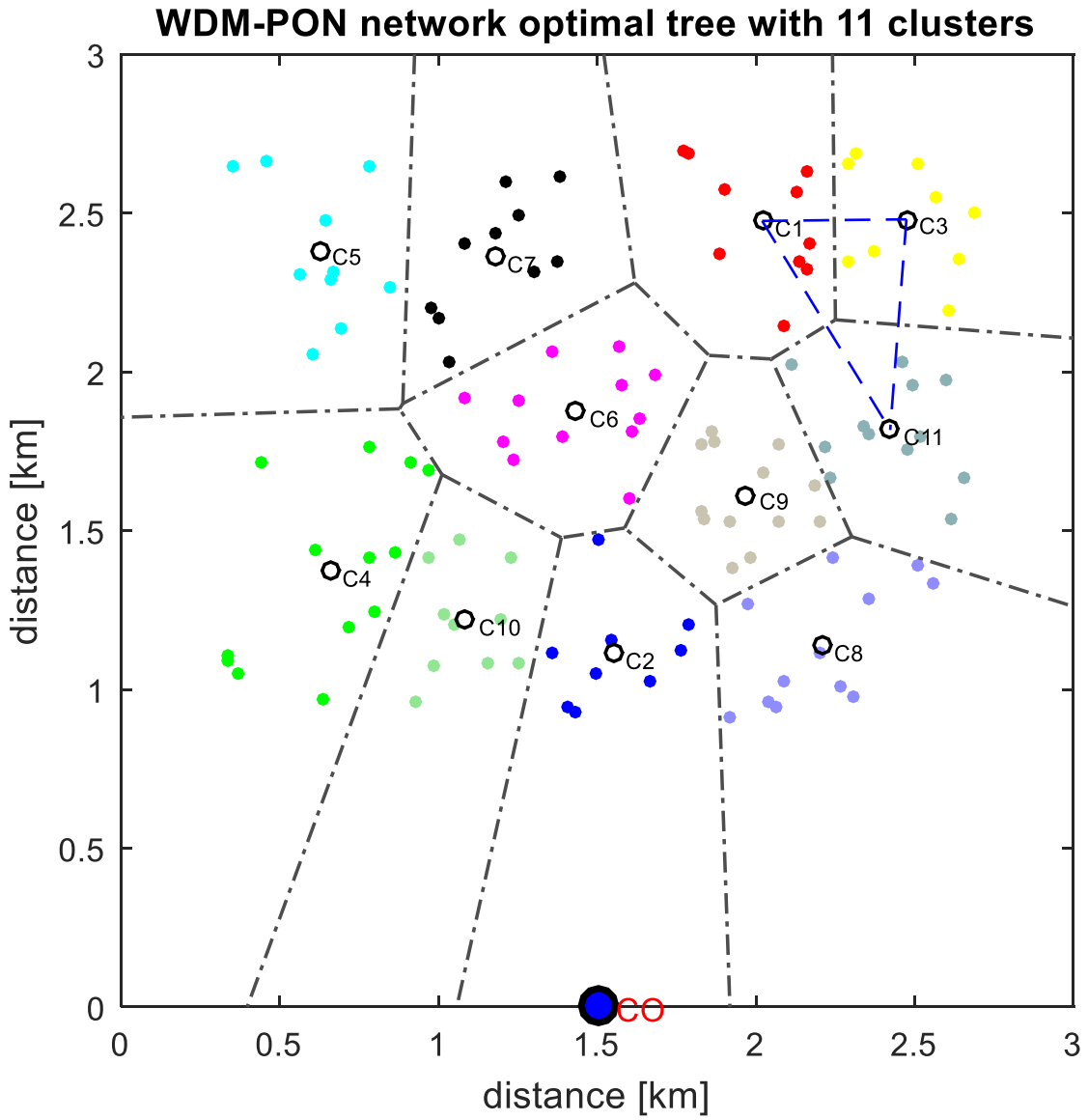


Delaunay triangle: The circumscribed circle do not contain any other cluster center other than the triangle vertices

Algorithm description



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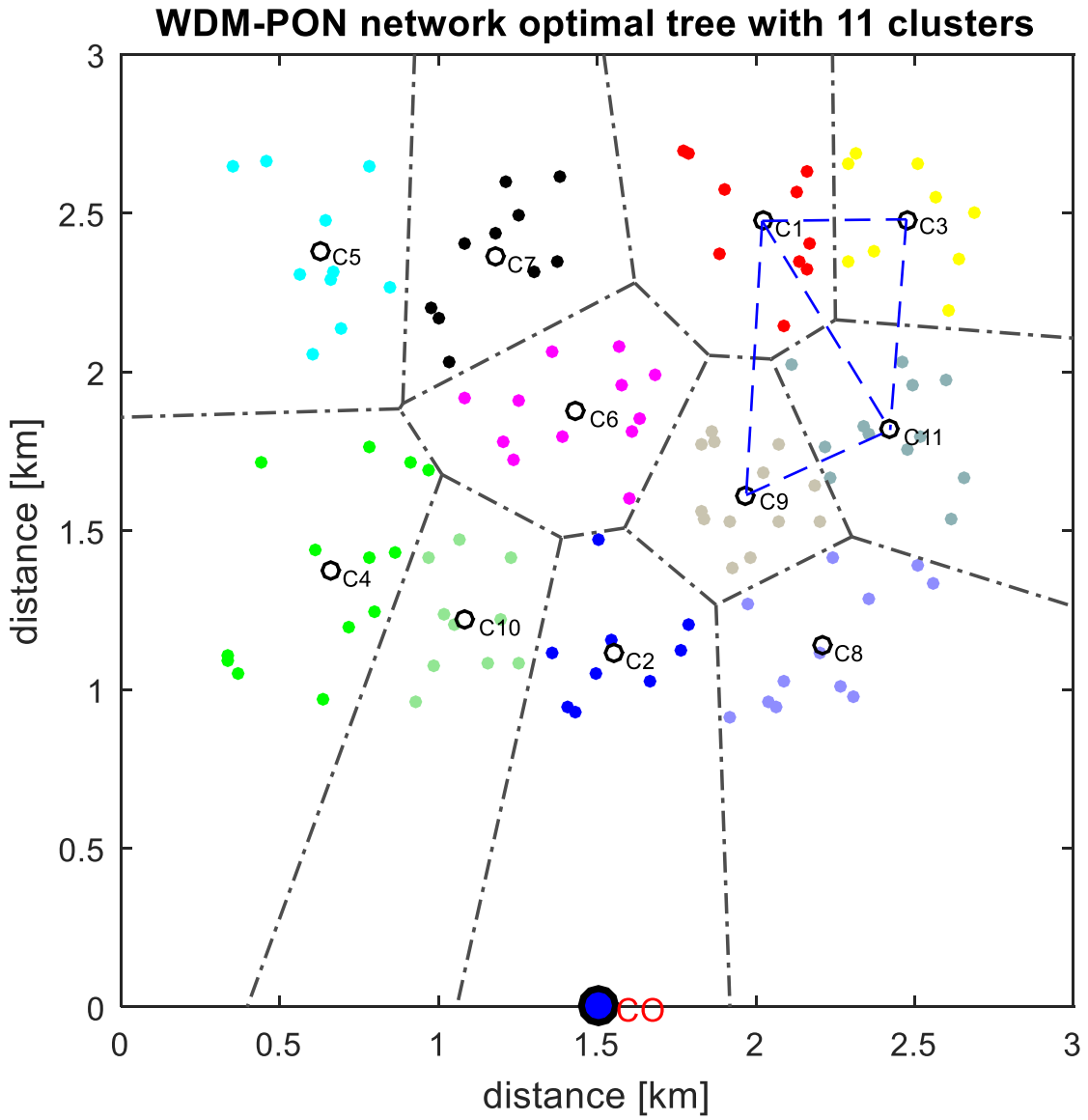

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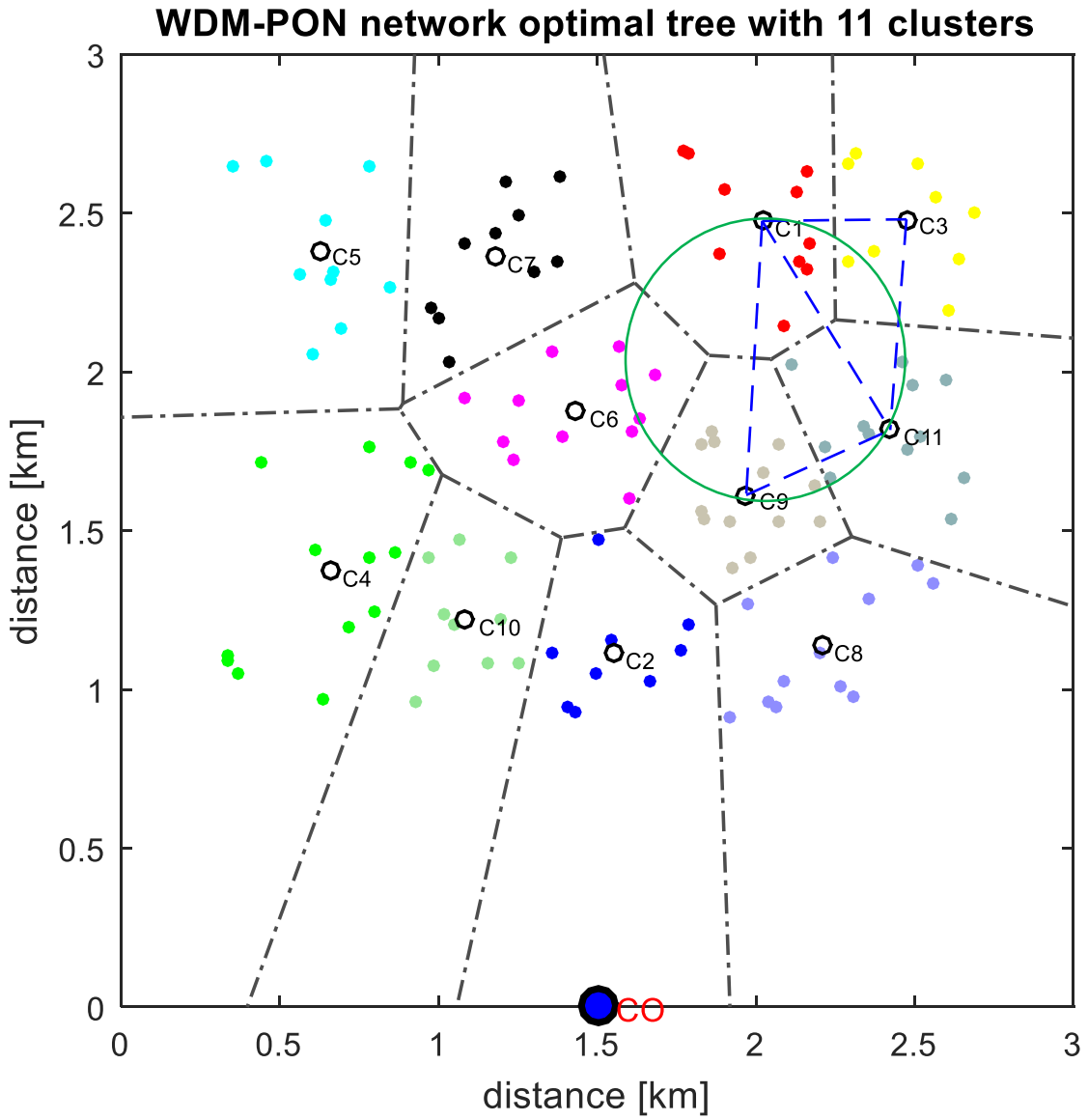

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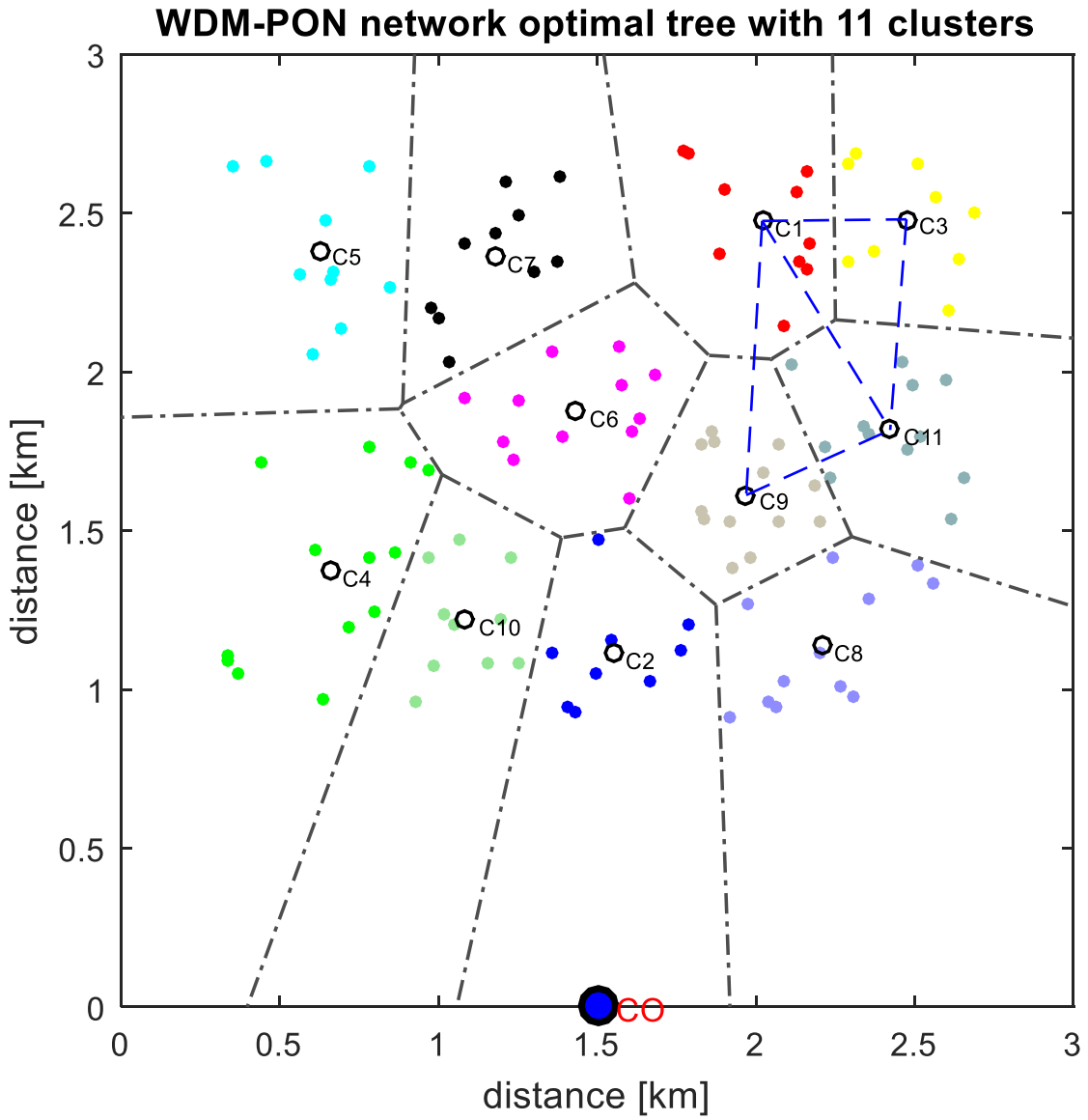

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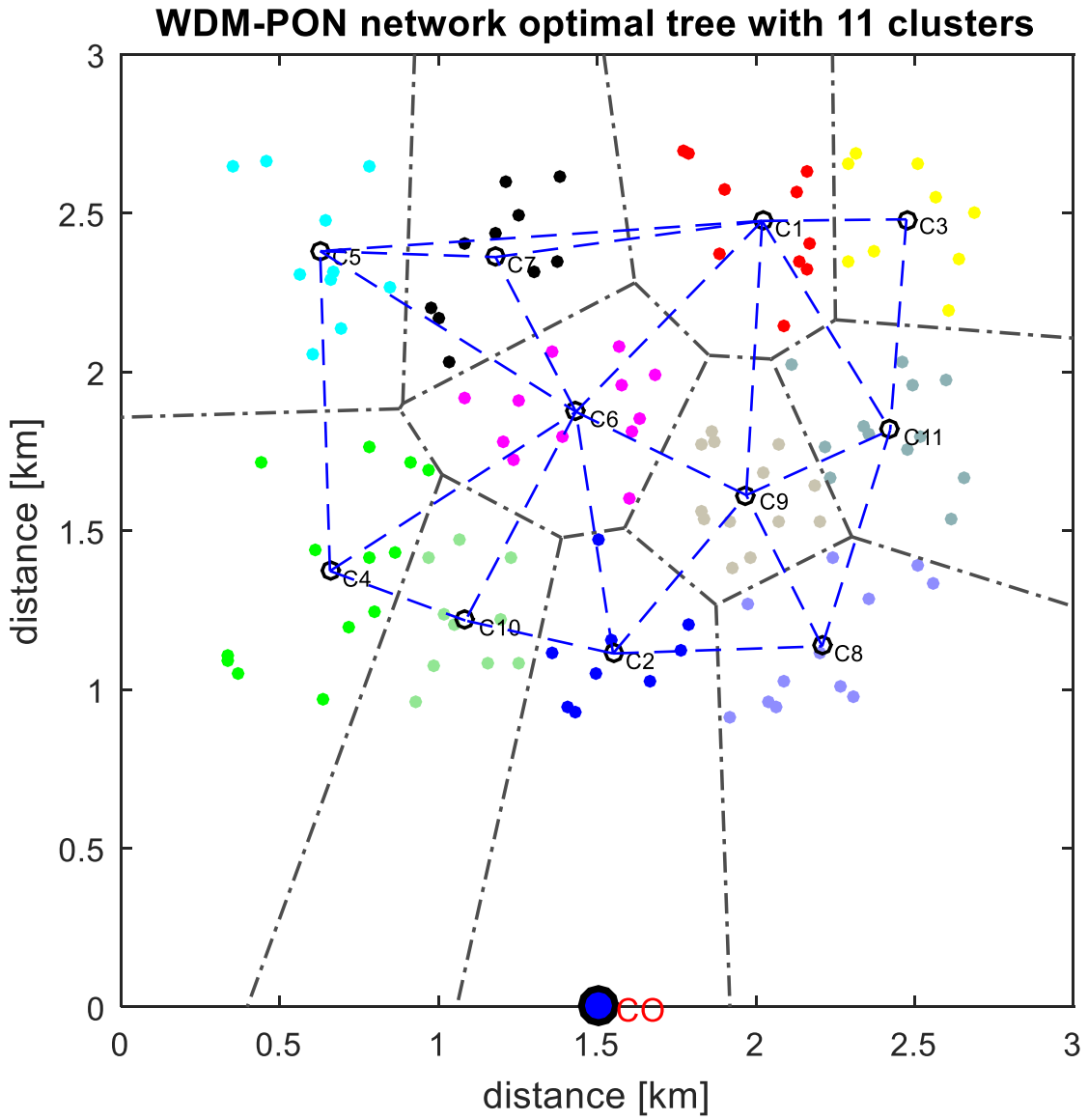

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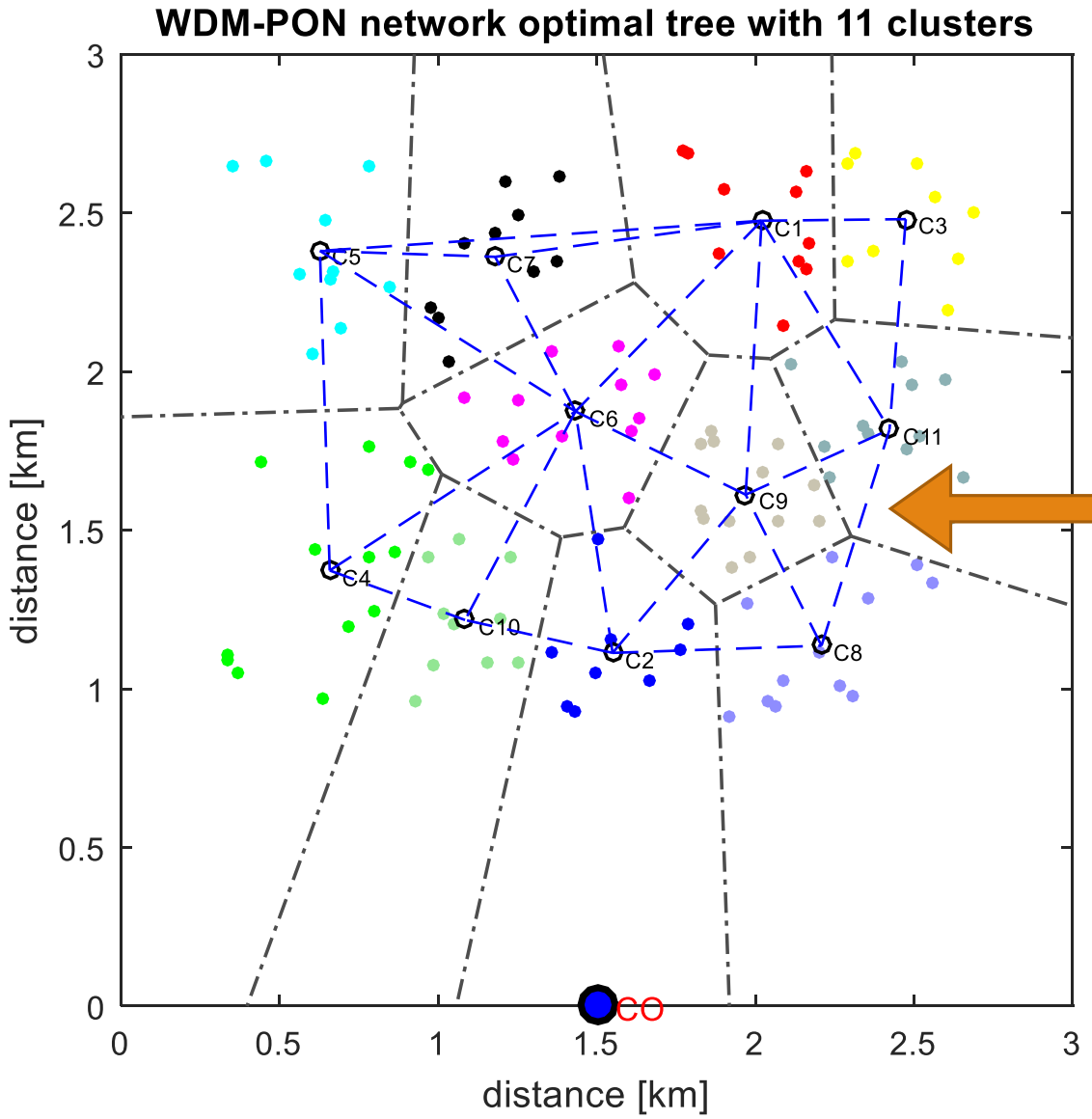
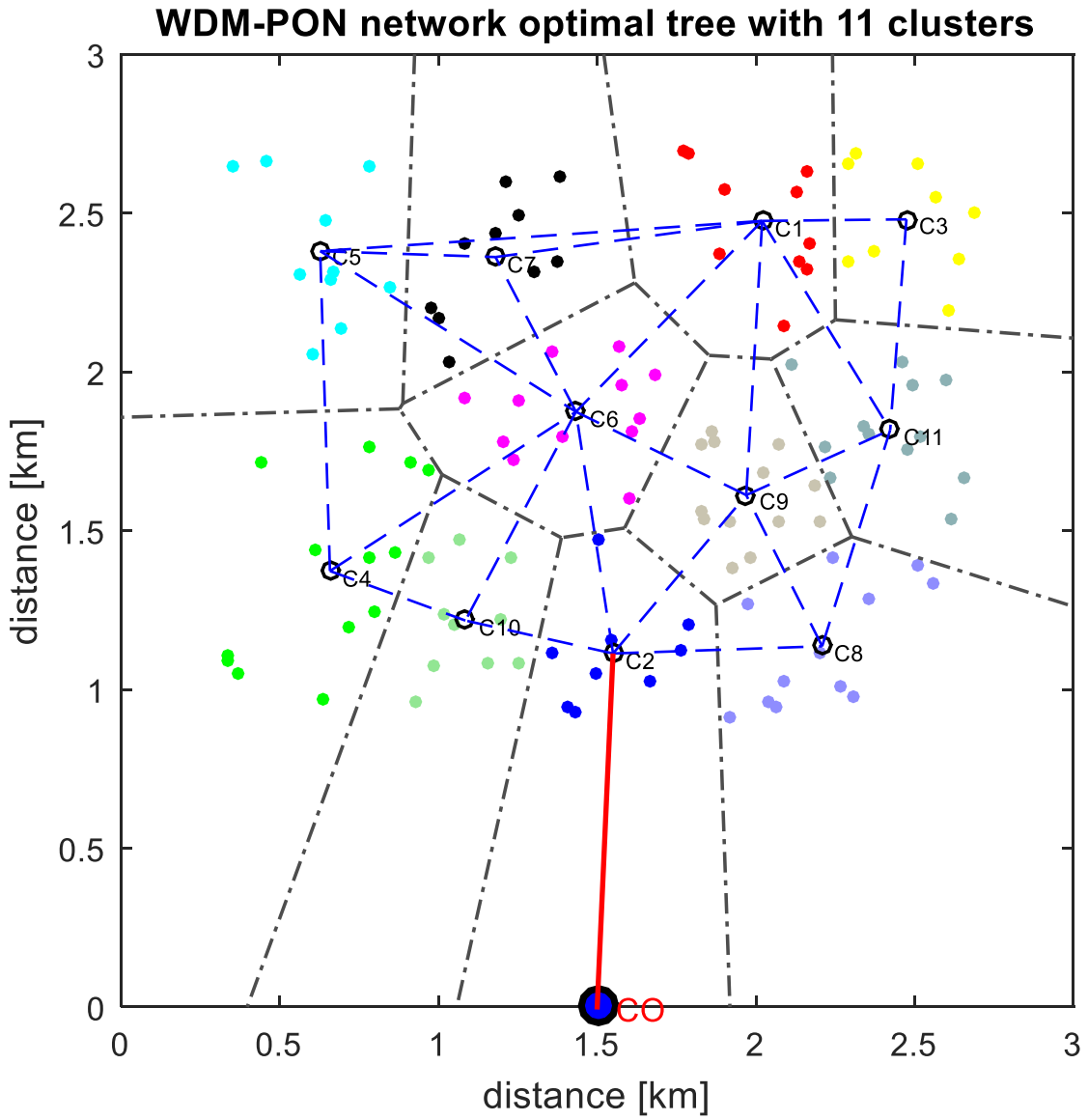


Delaunay's Triangulation

Algorithm description



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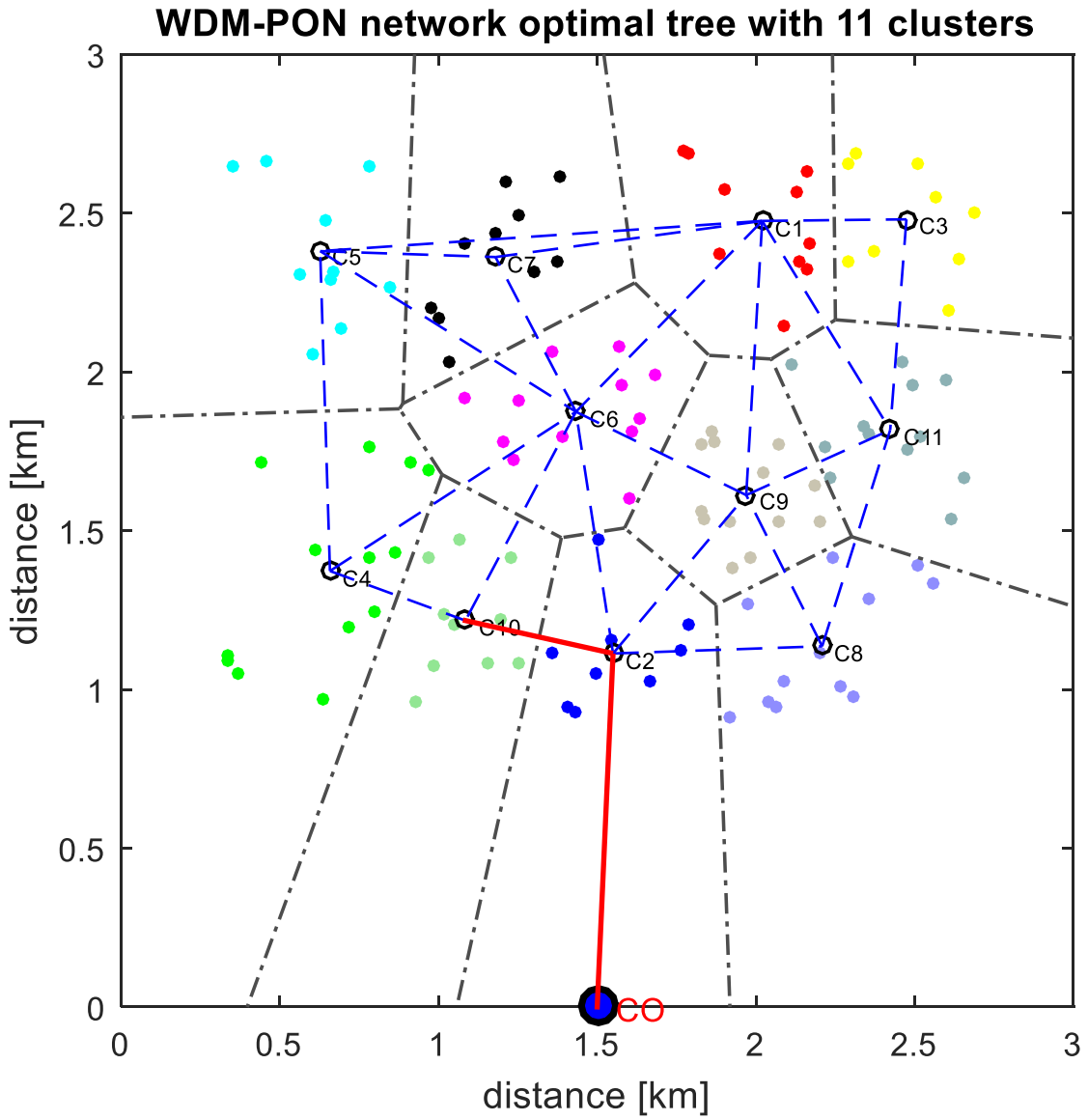

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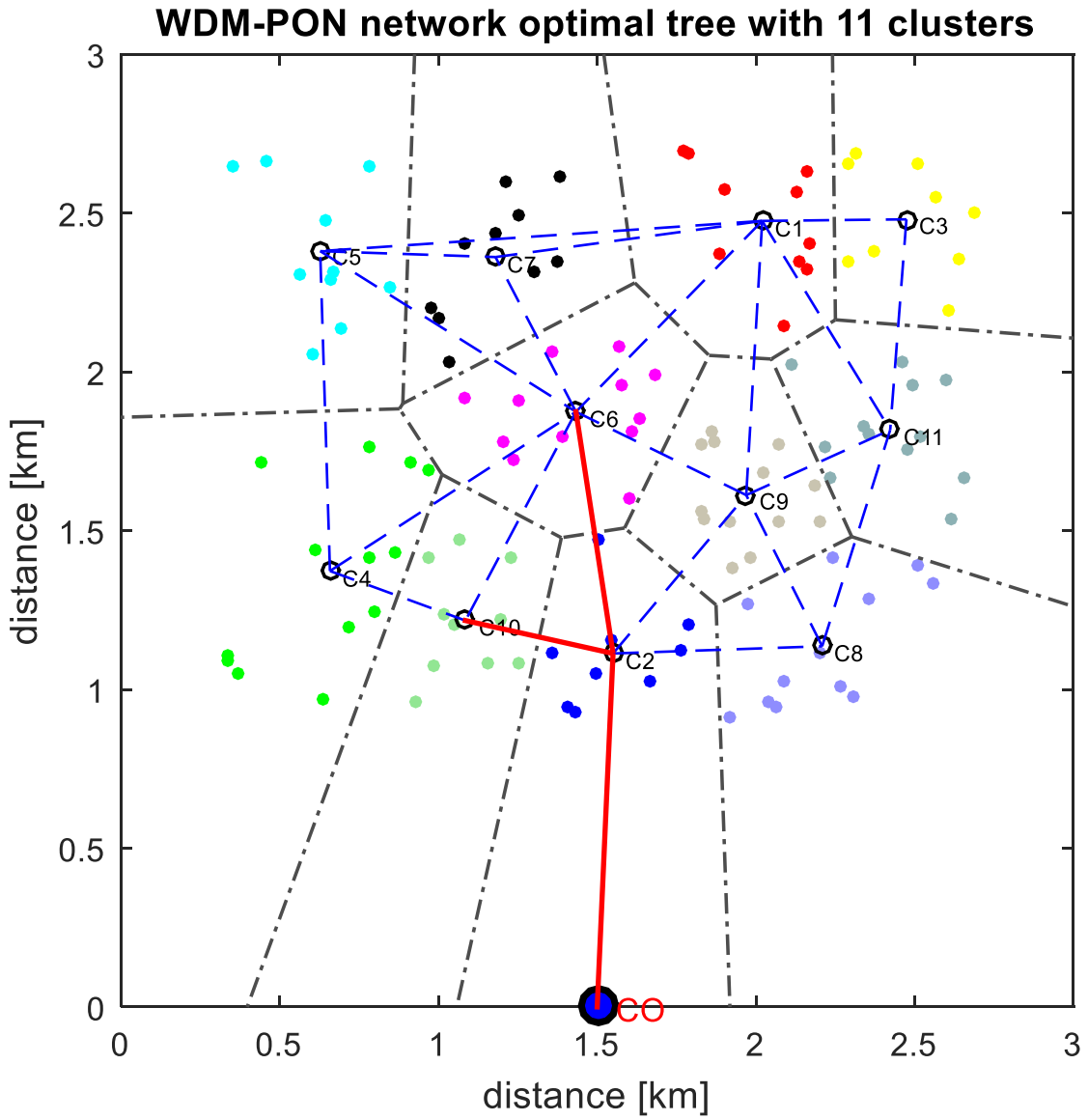

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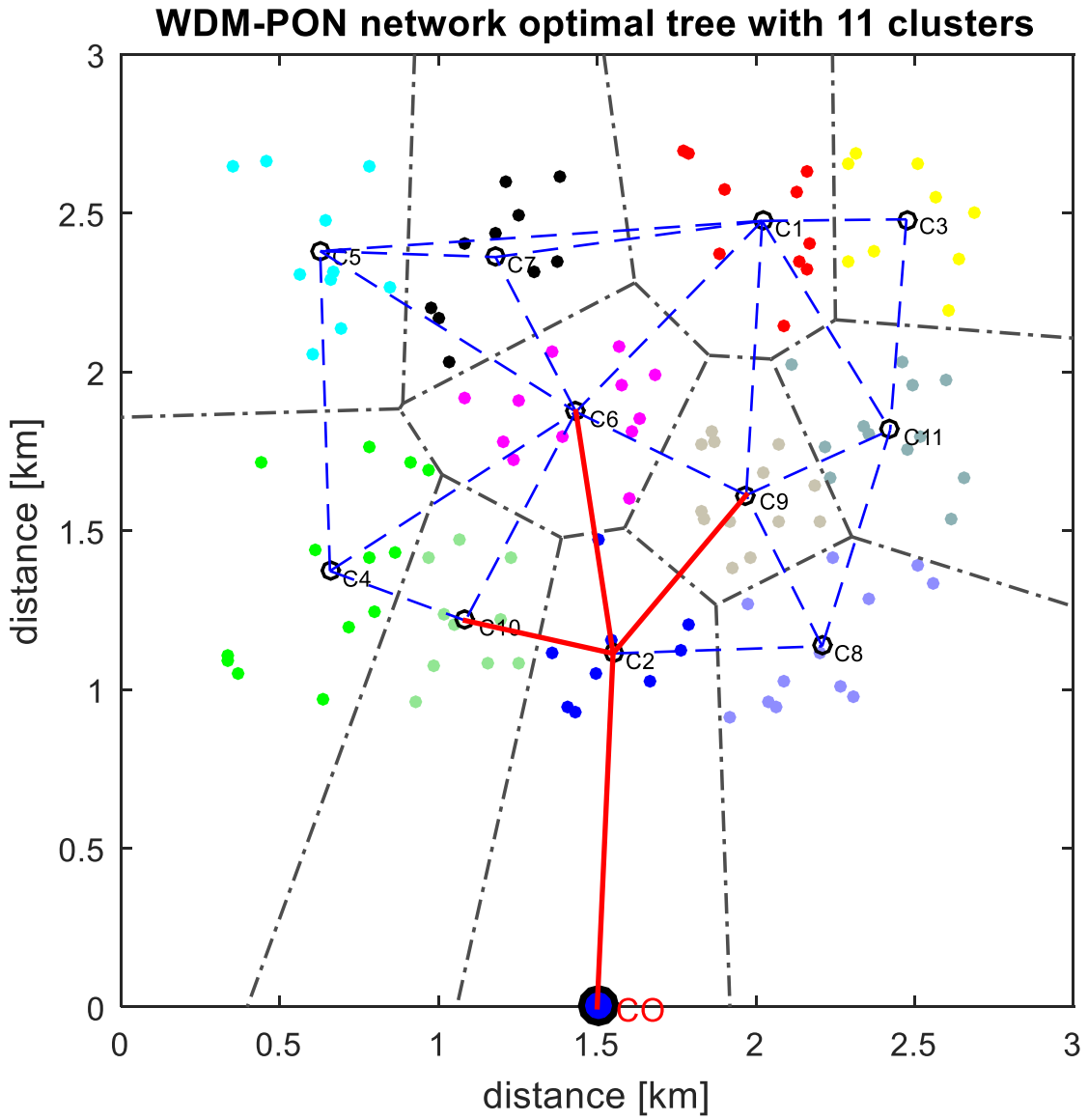

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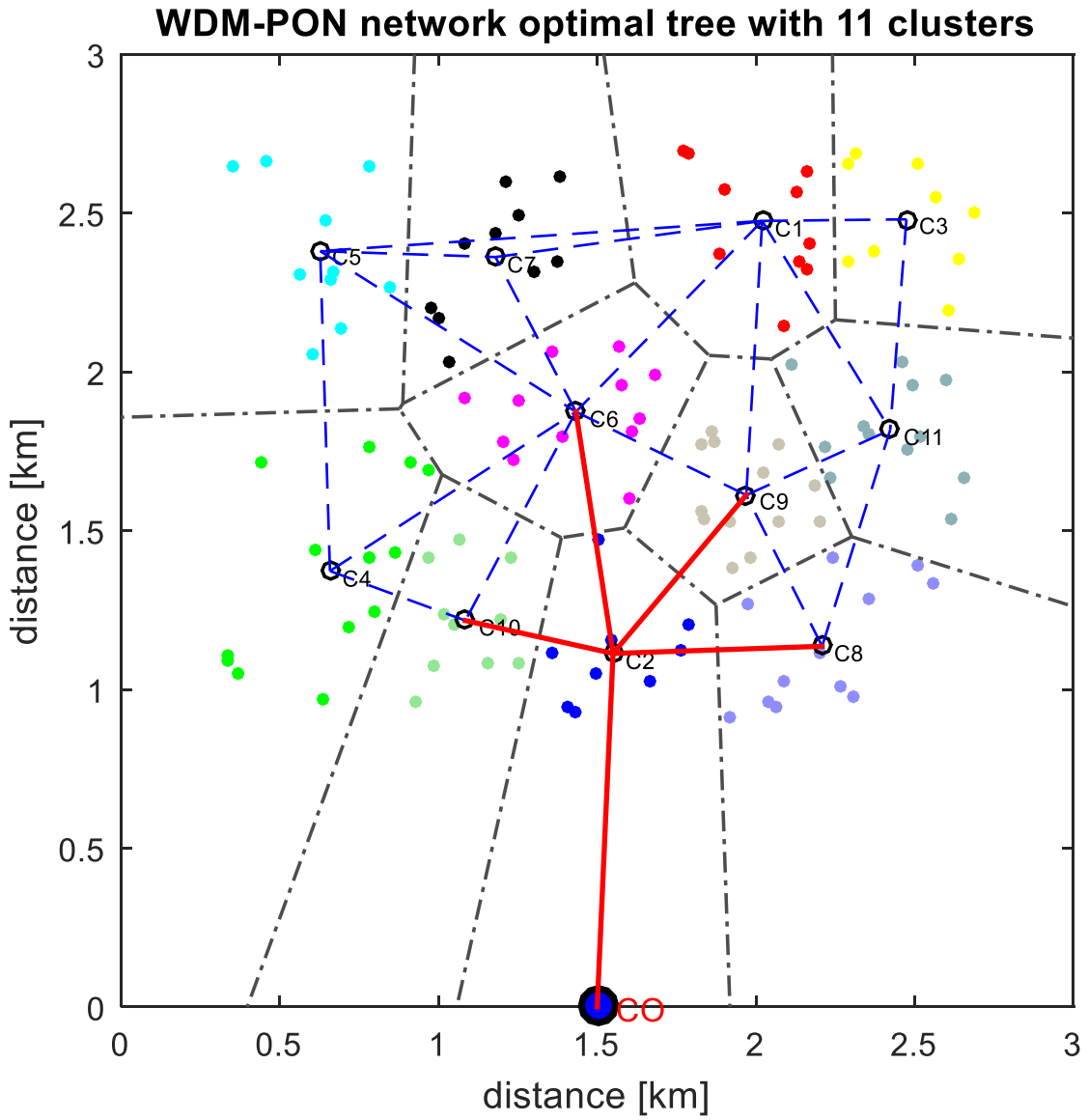

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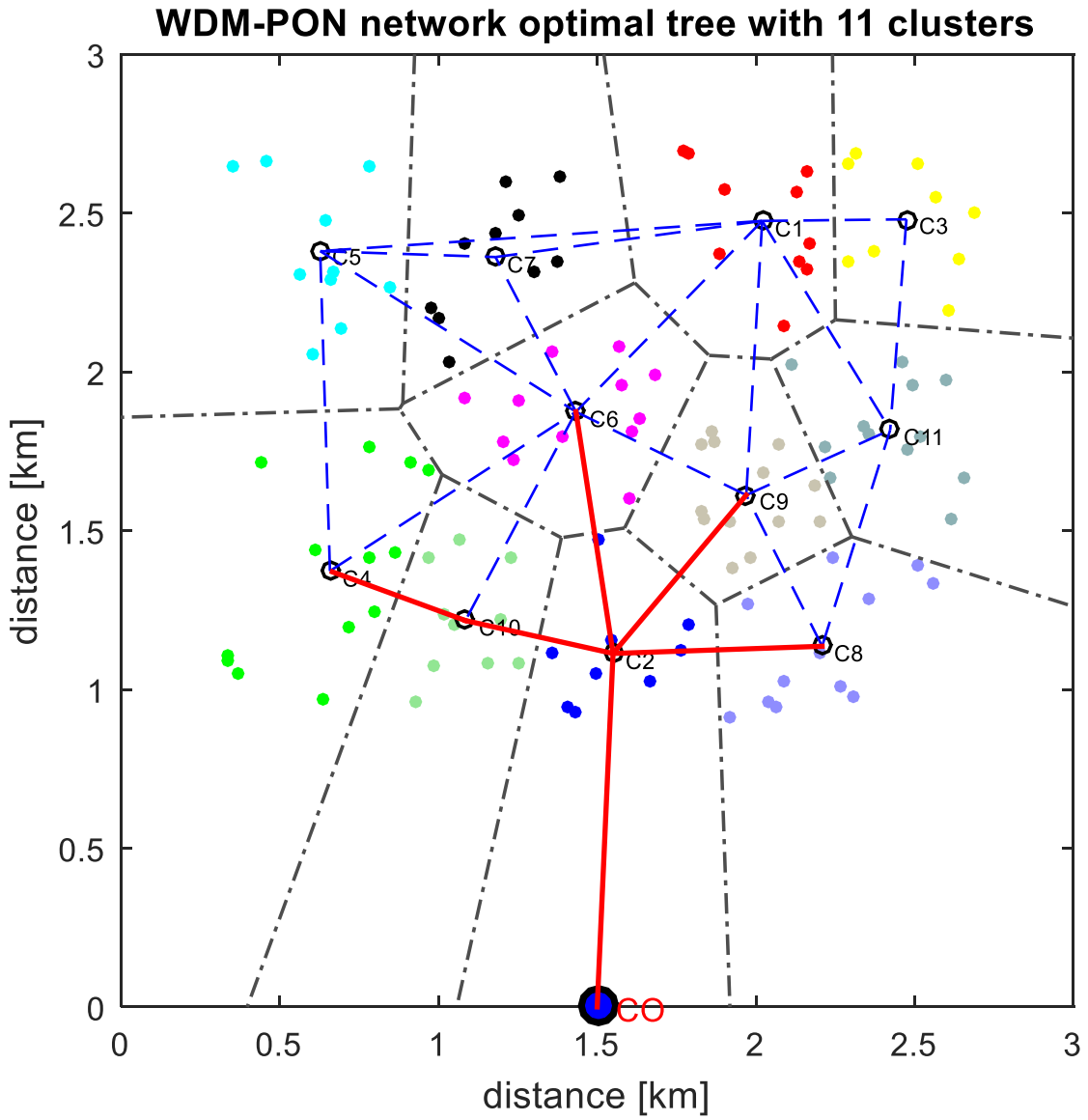

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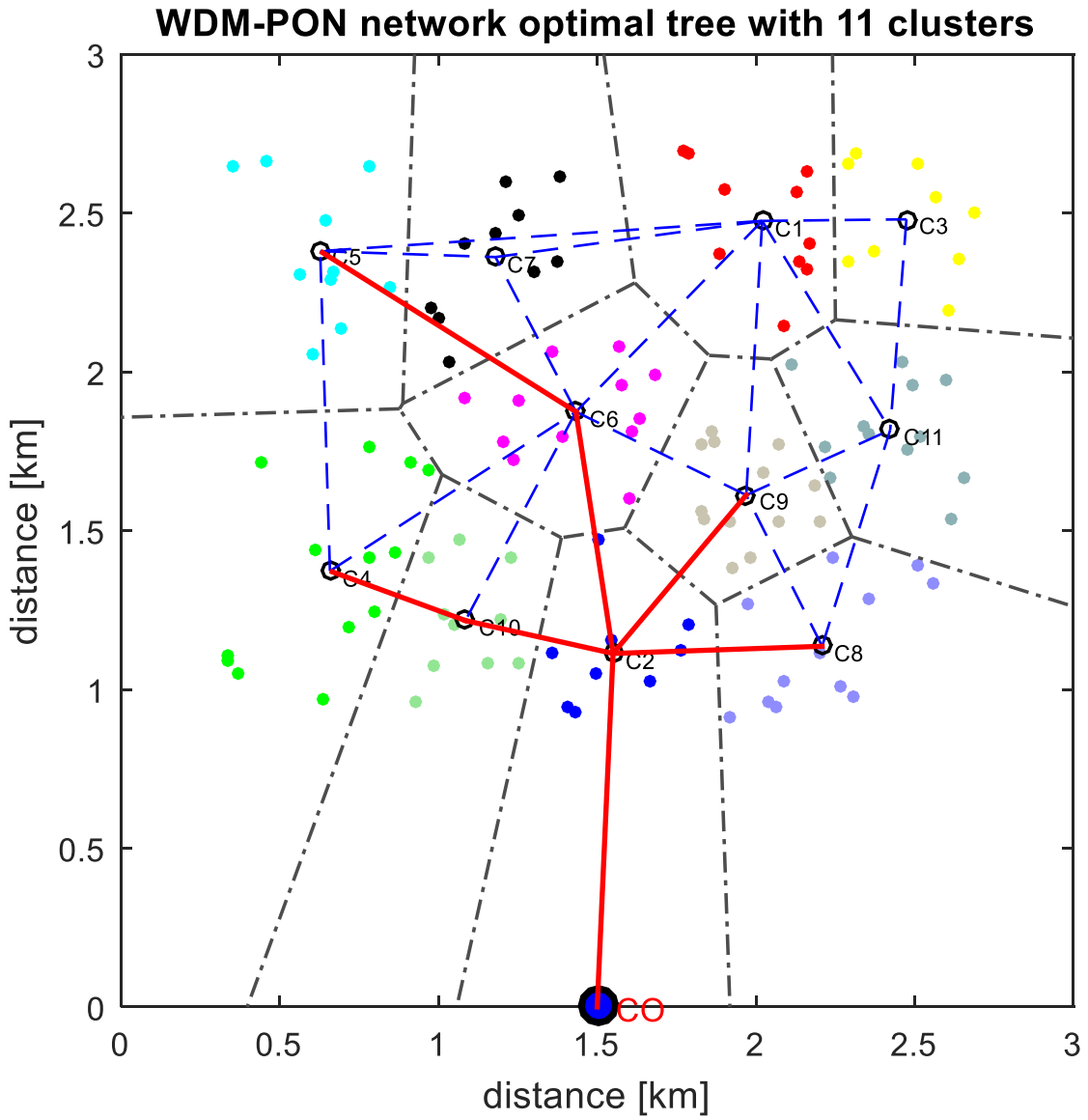

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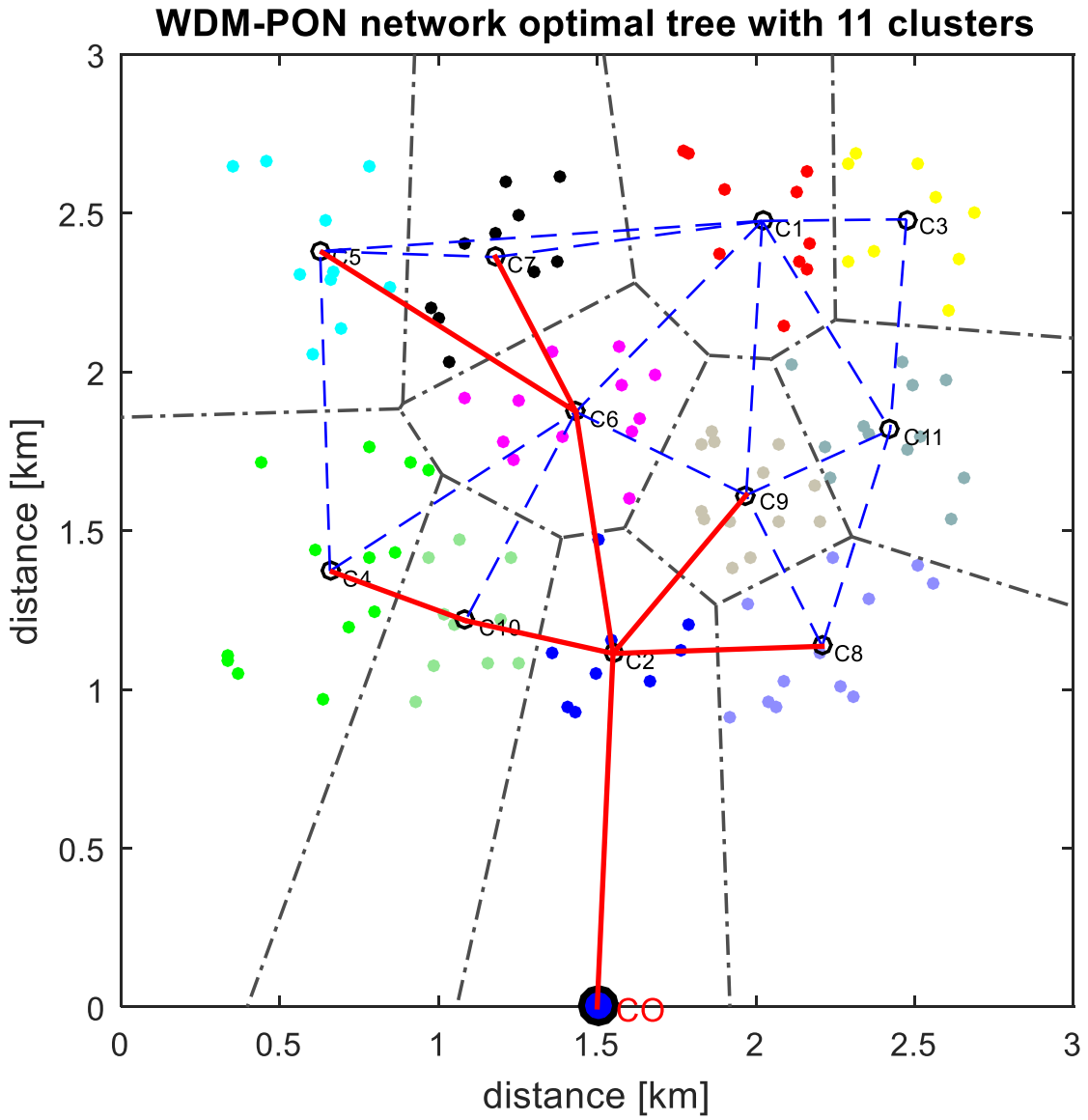

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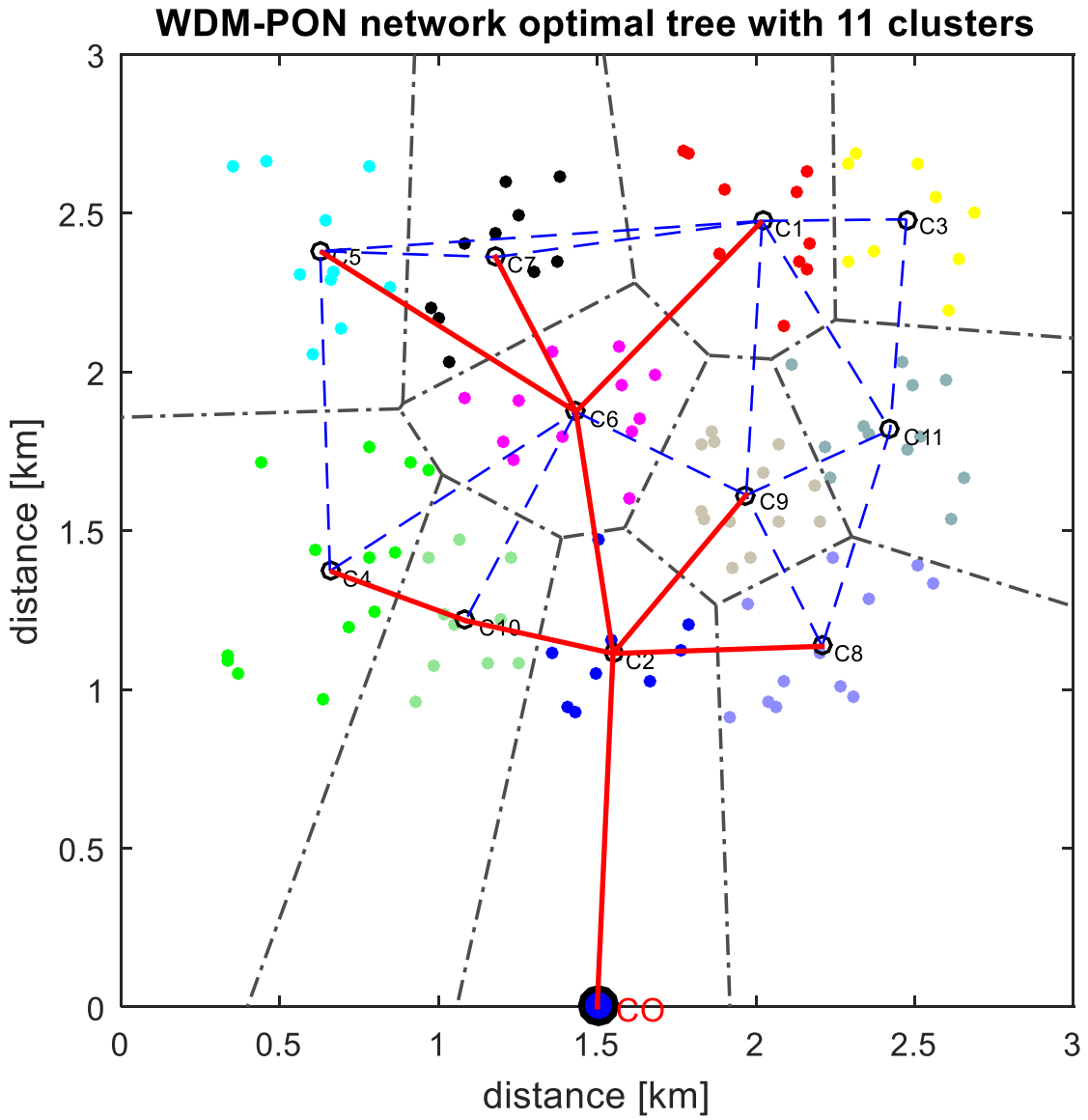

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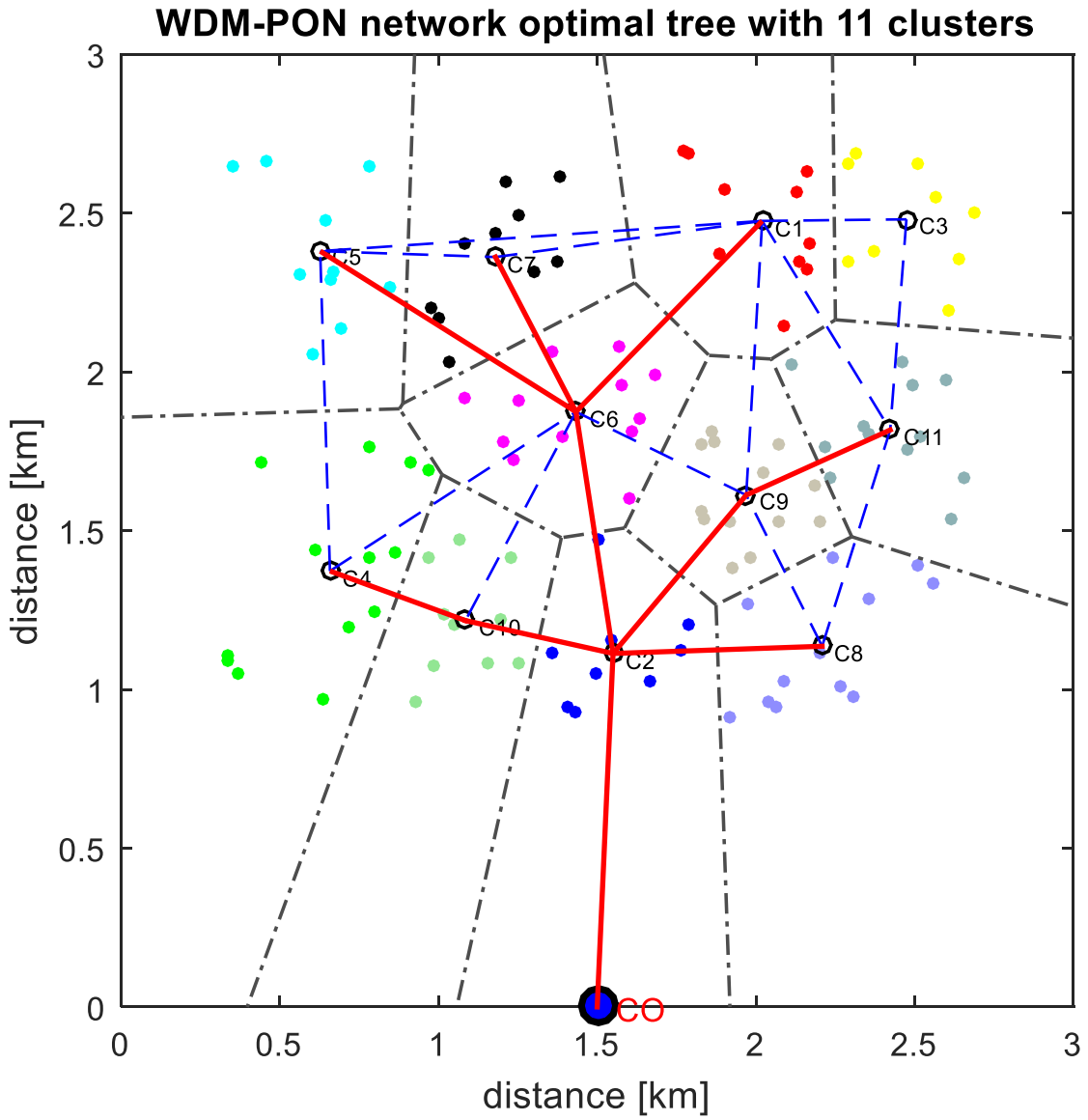

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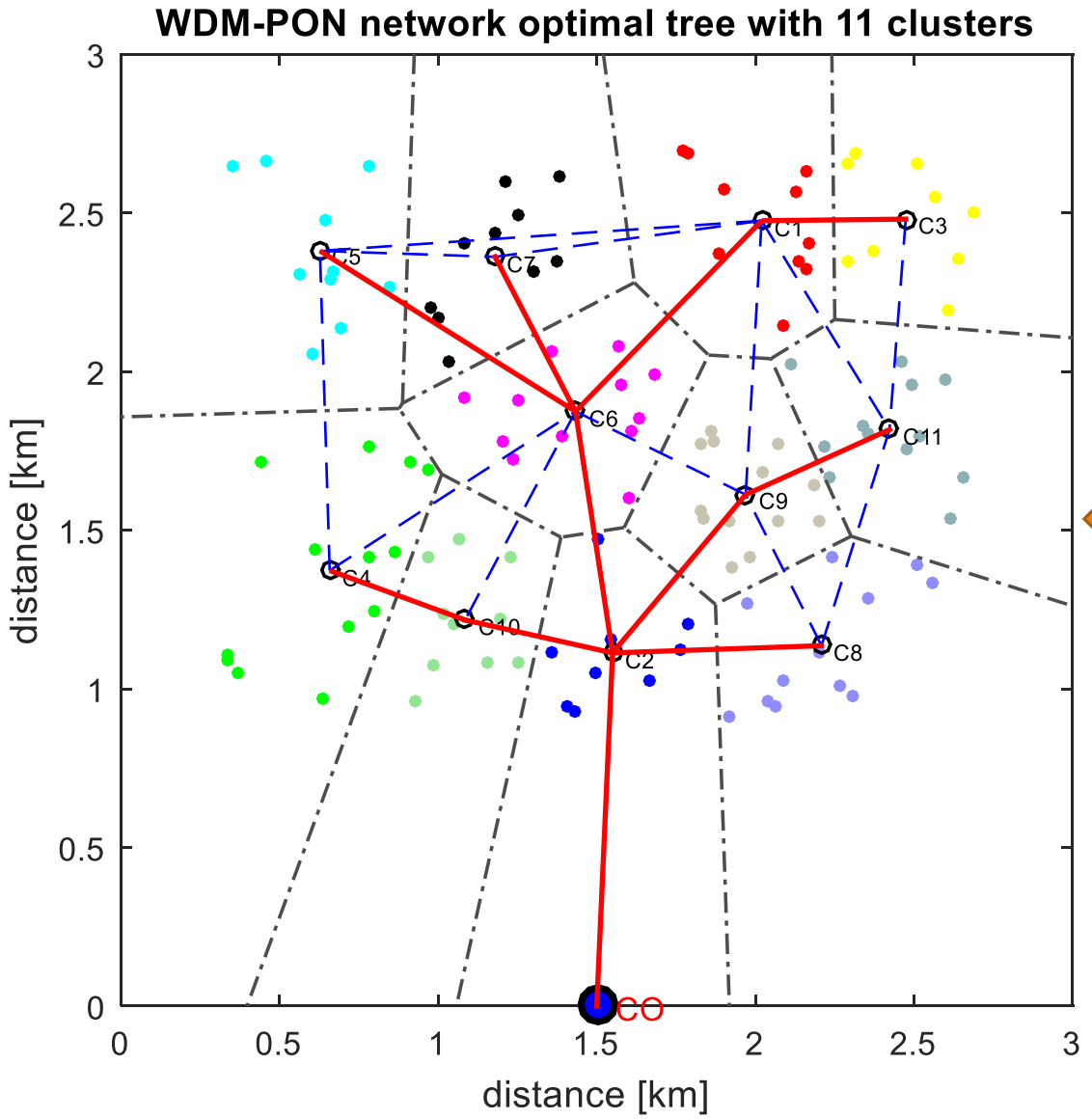
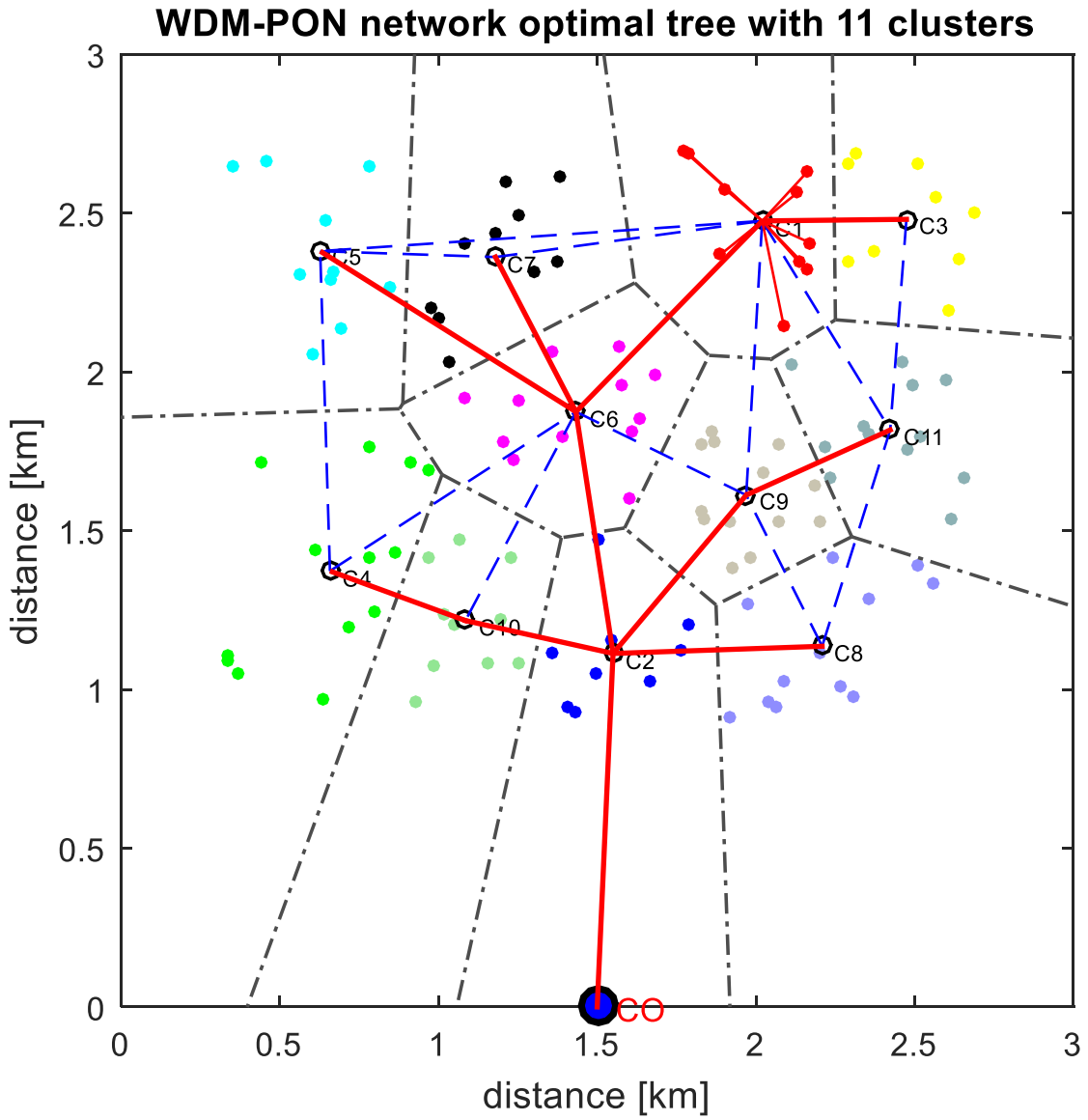


Modified Prim's algorithm

Algorithm description



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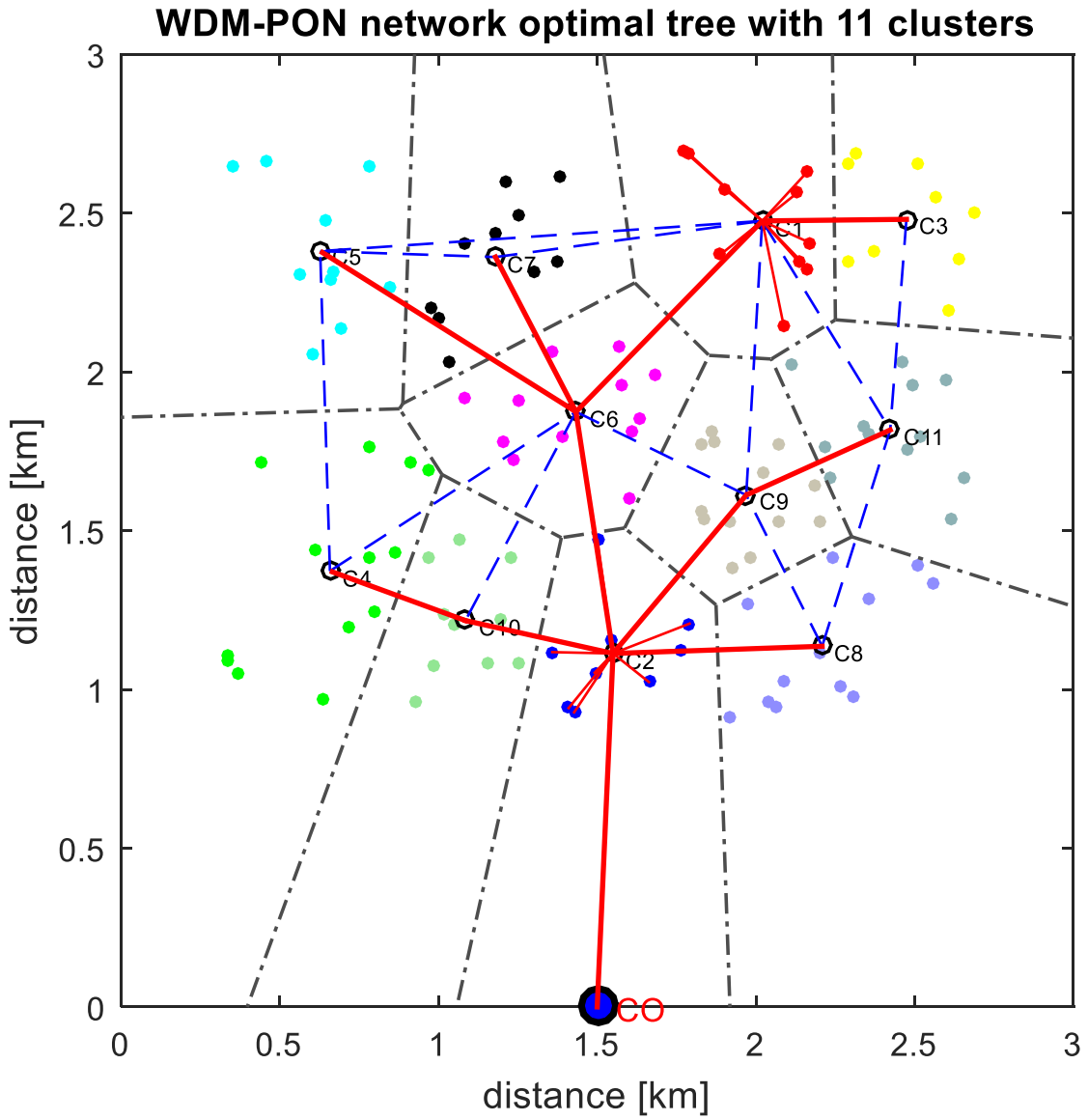

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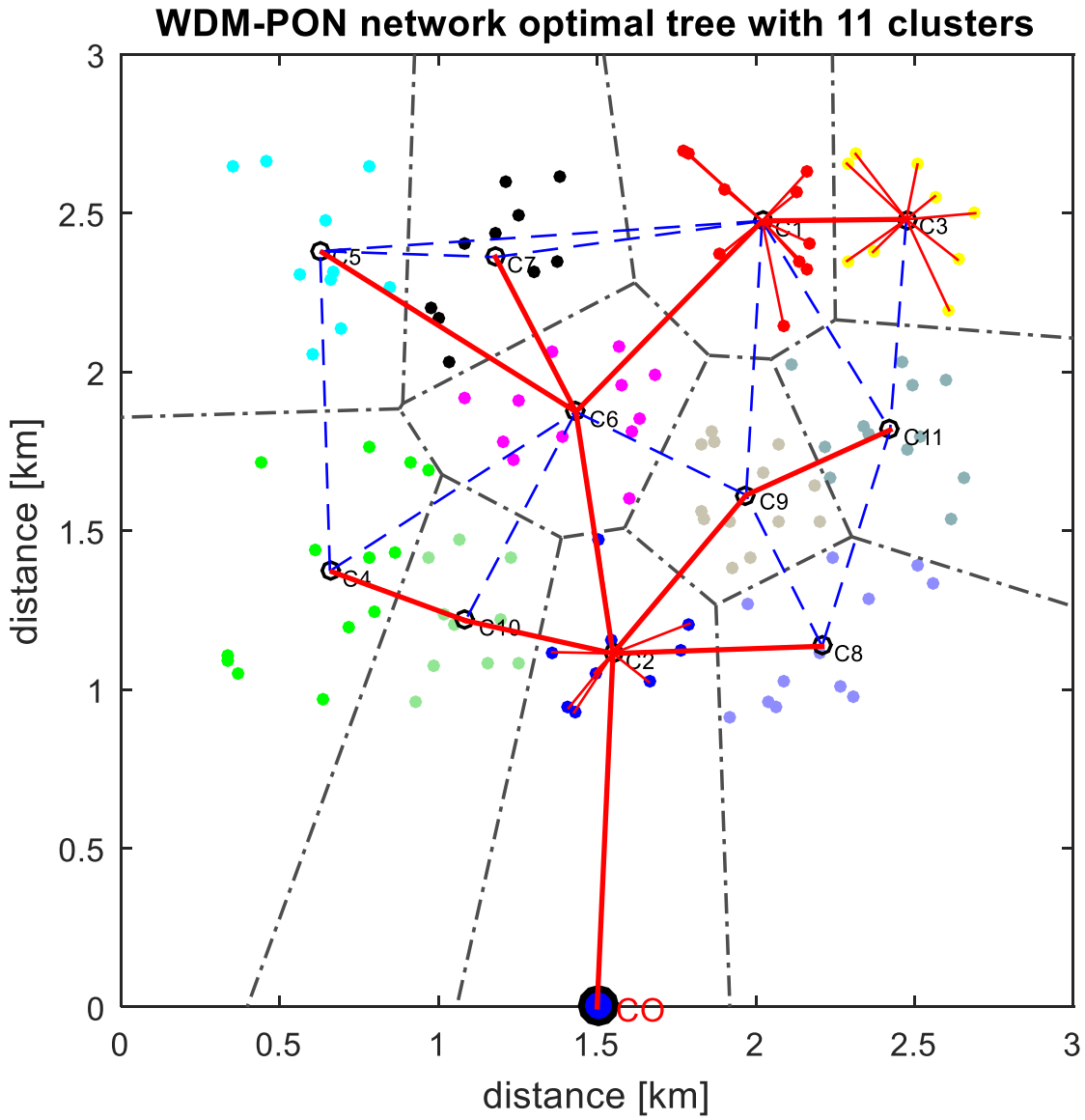

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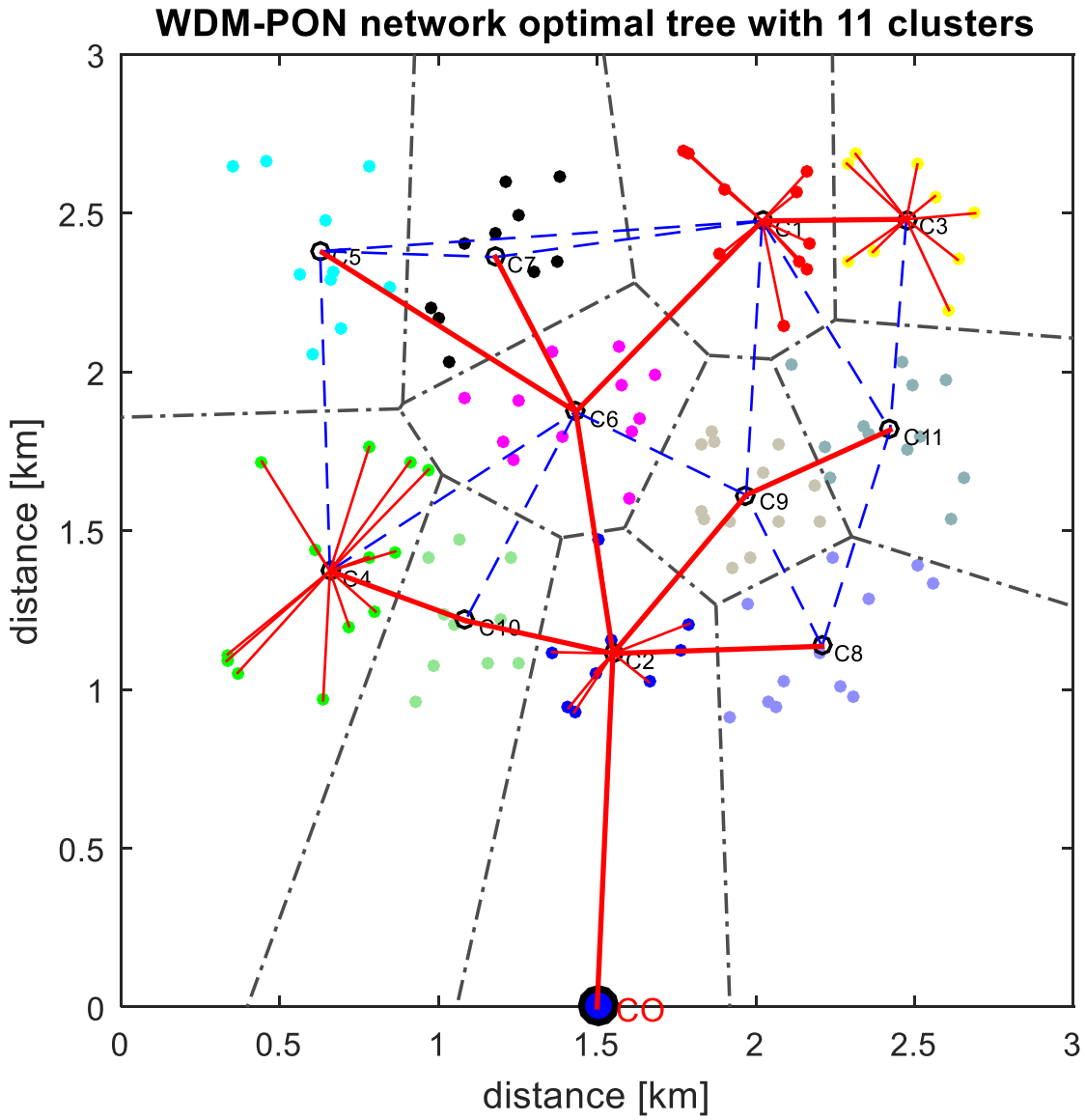

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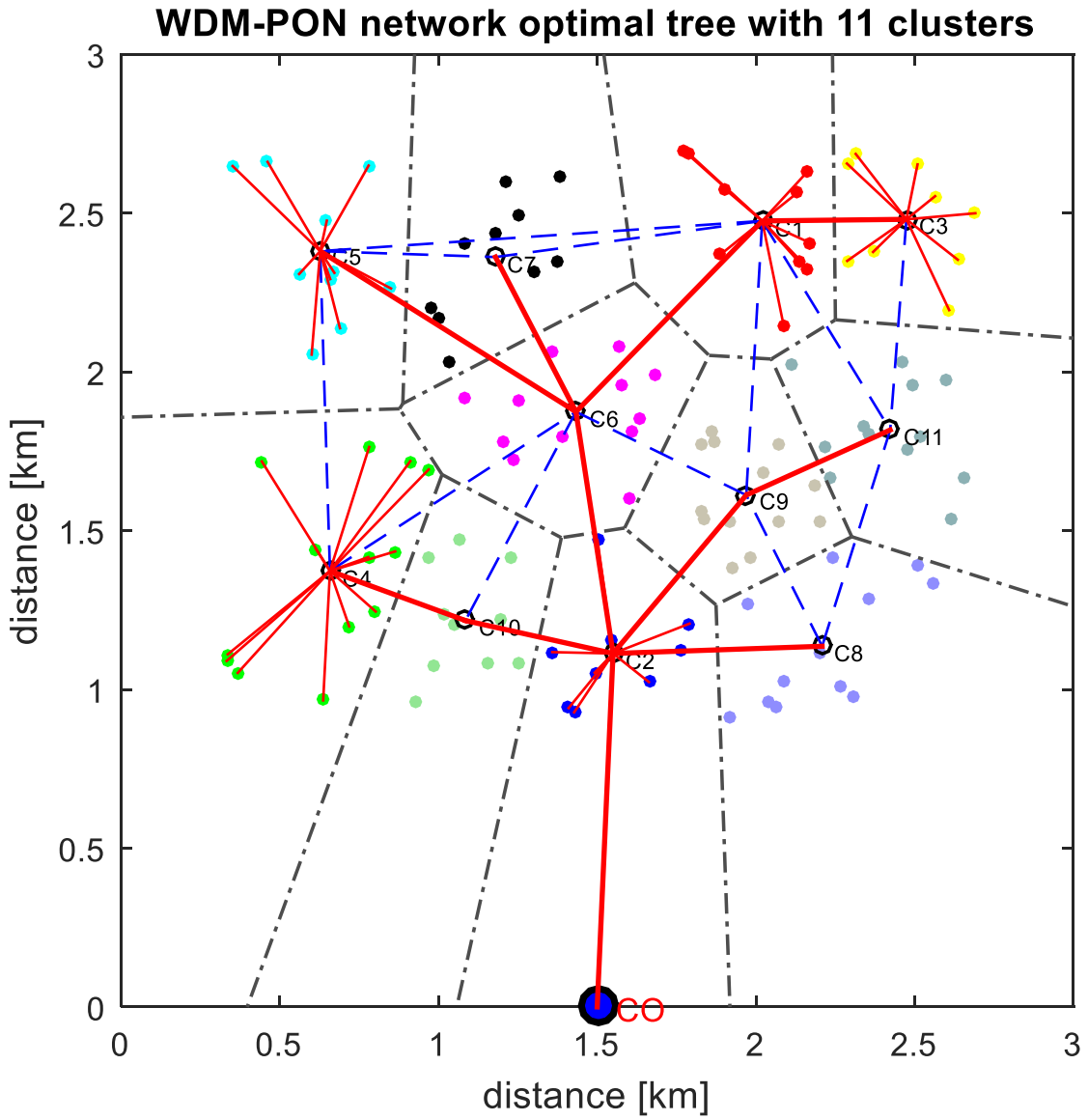

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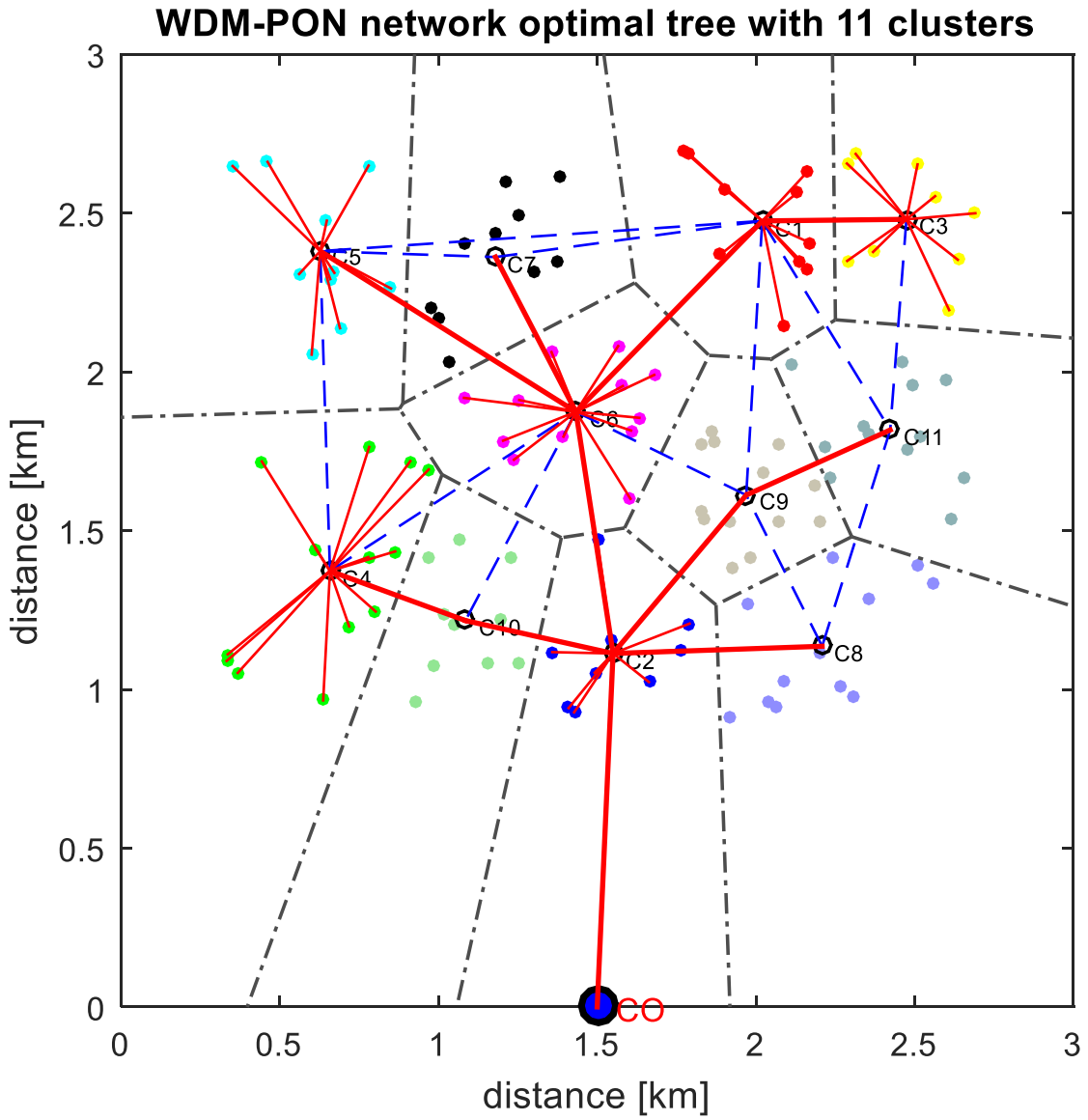

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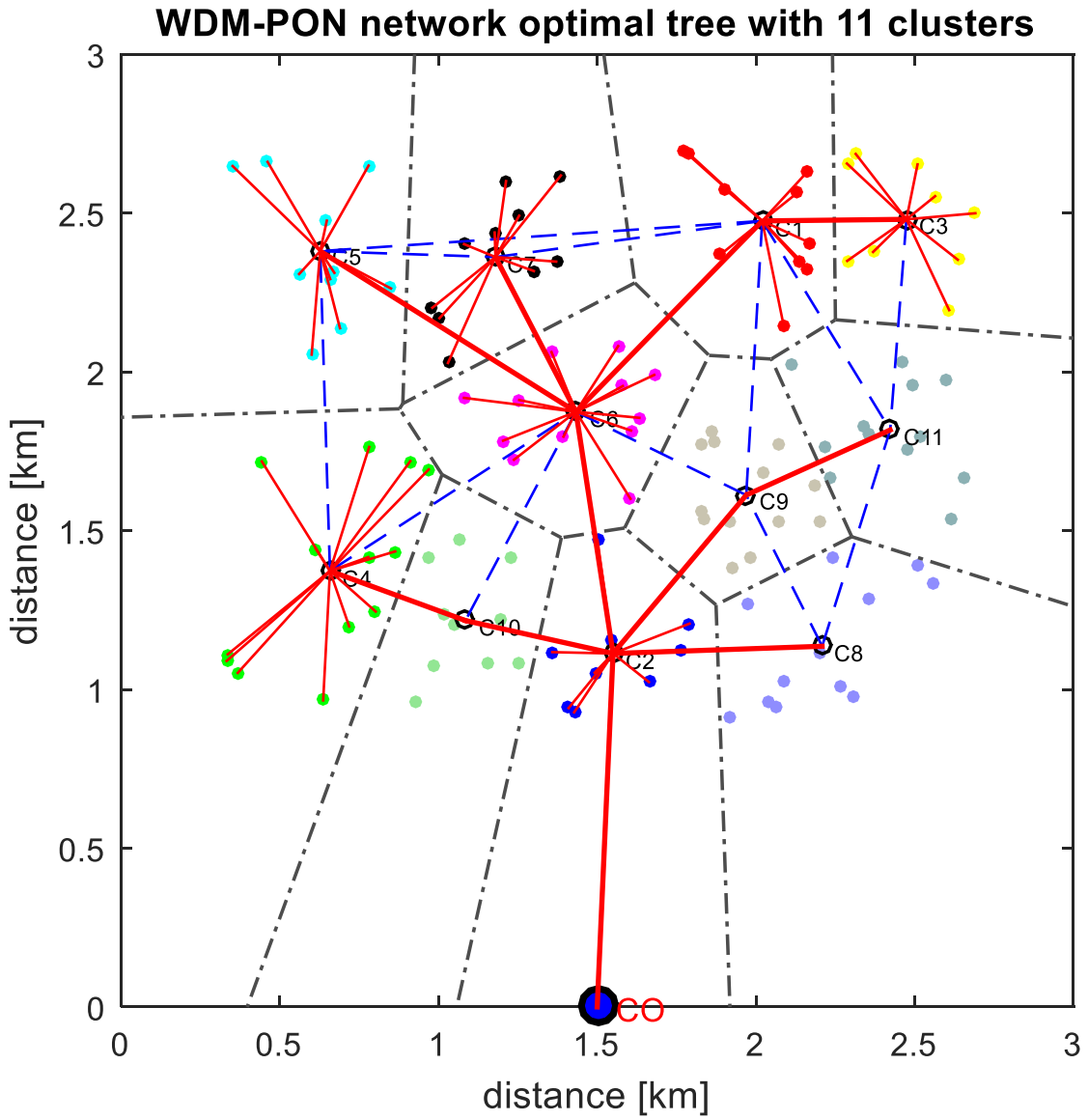

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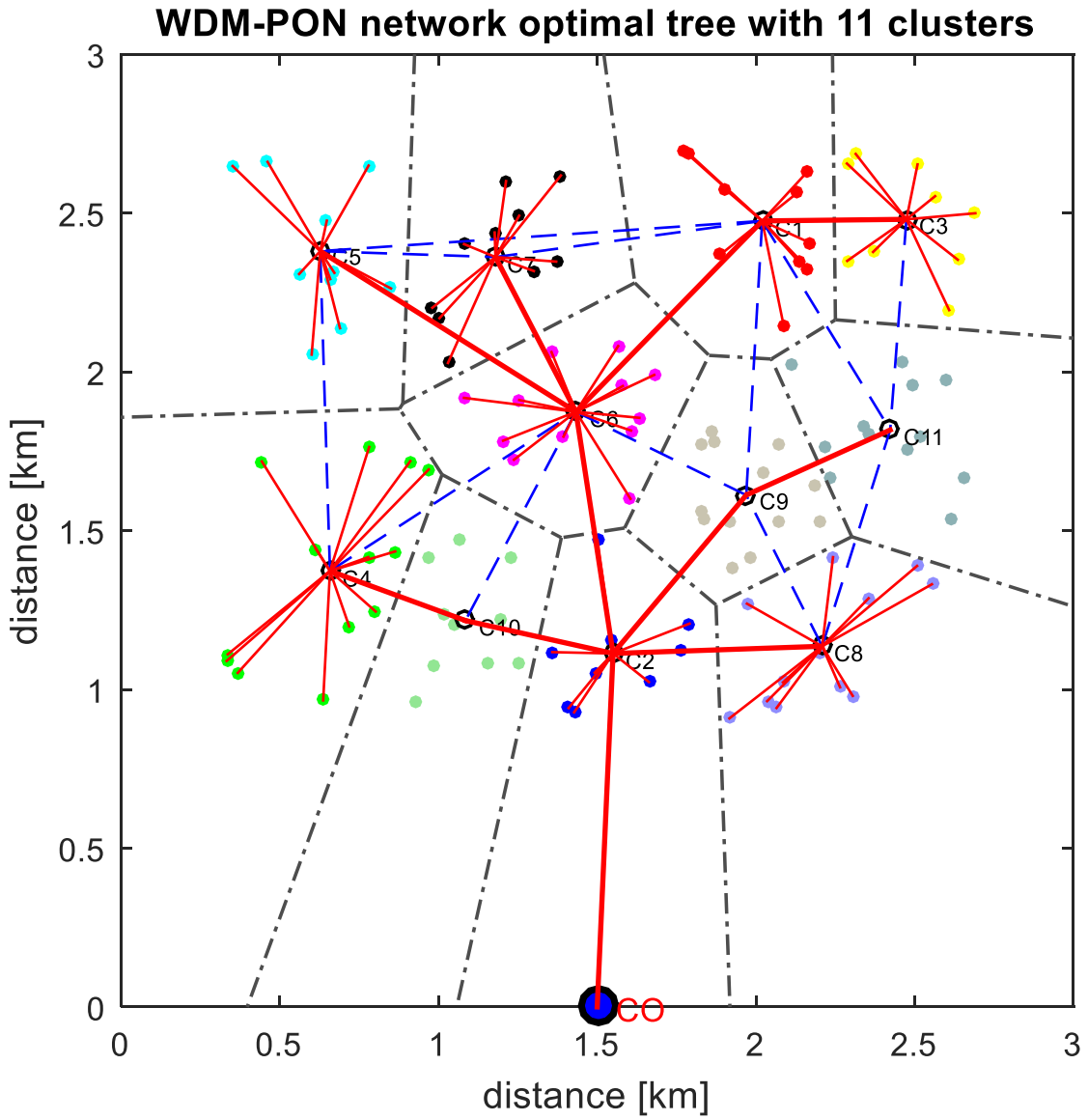

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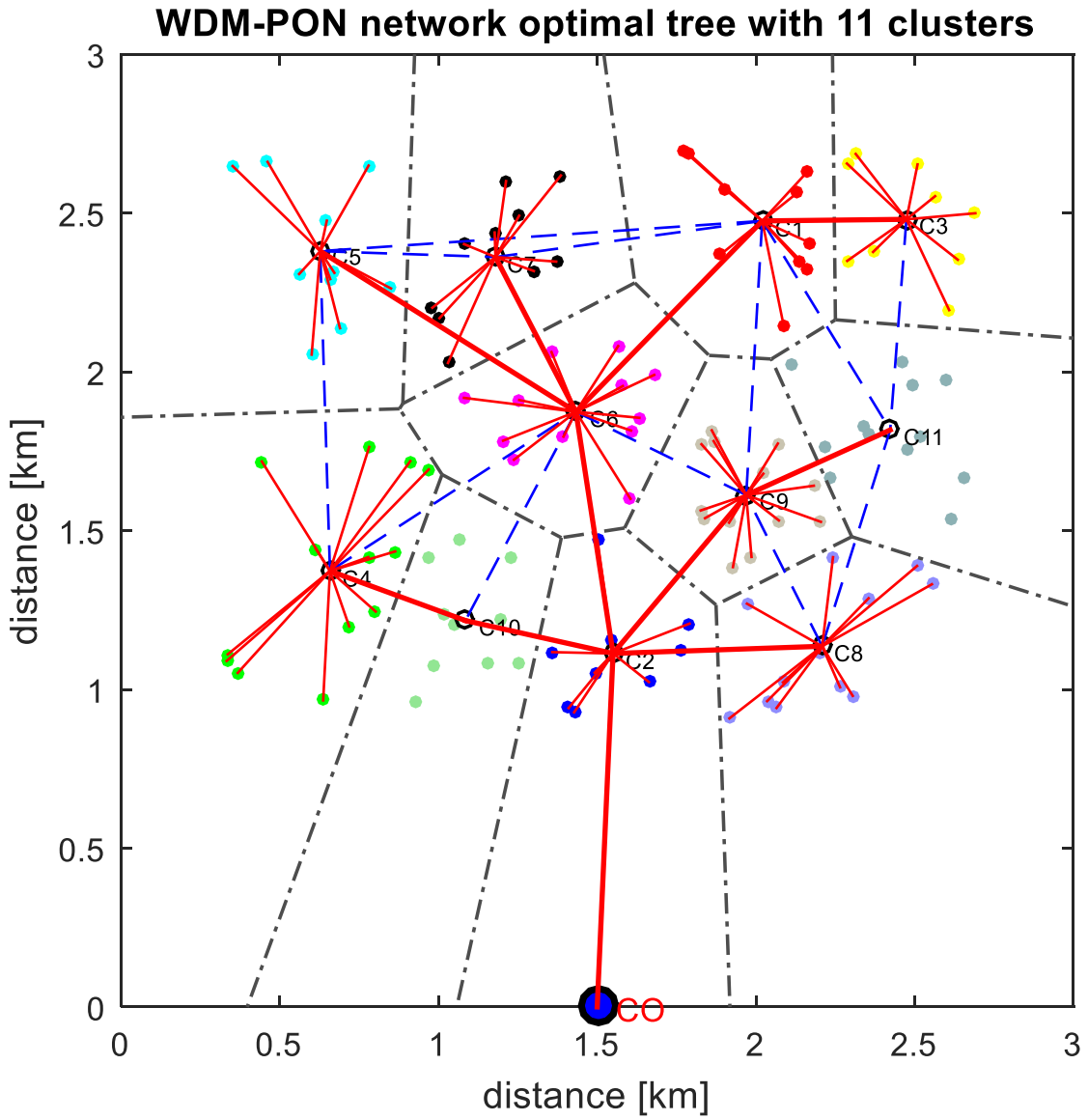
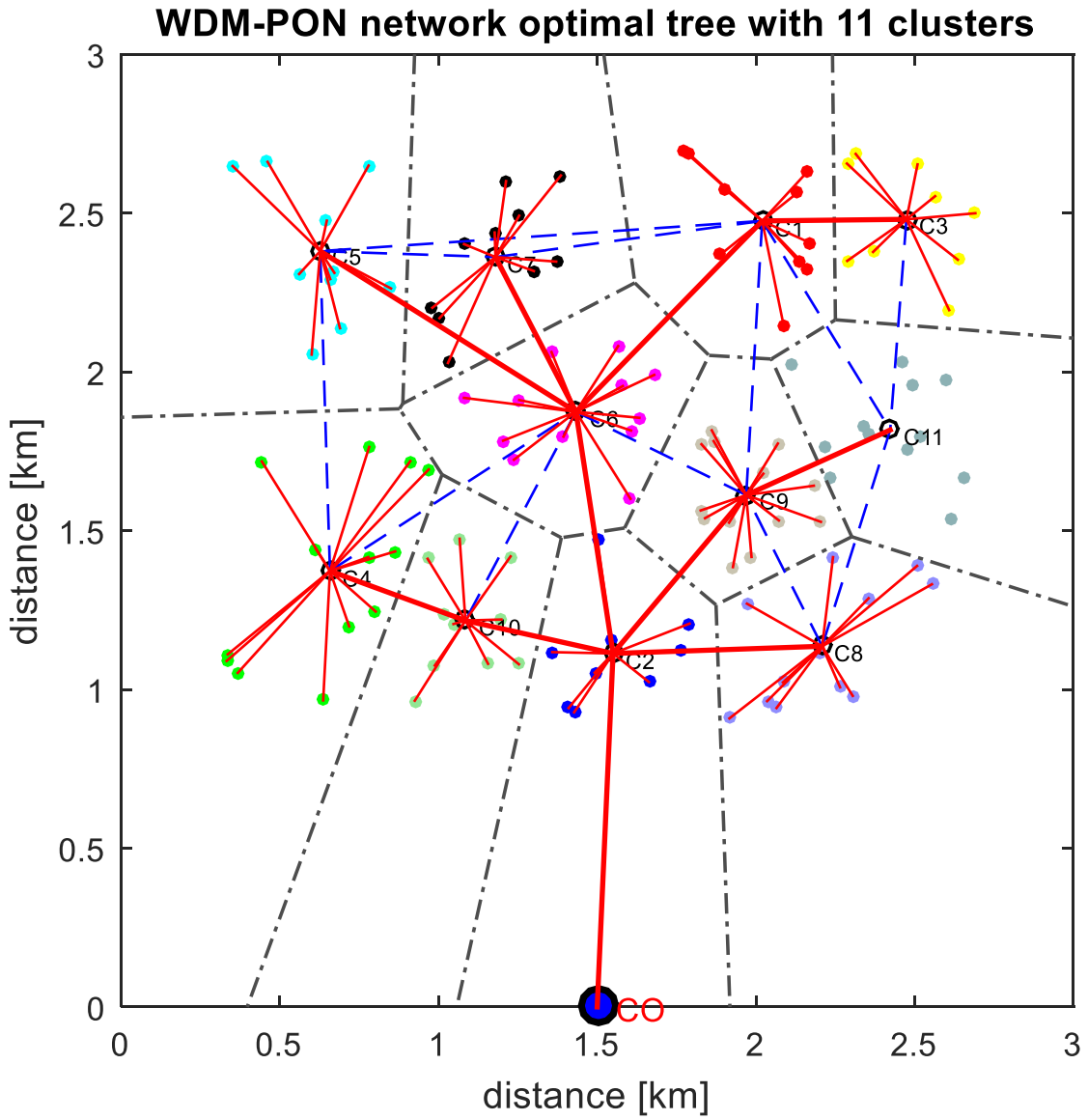
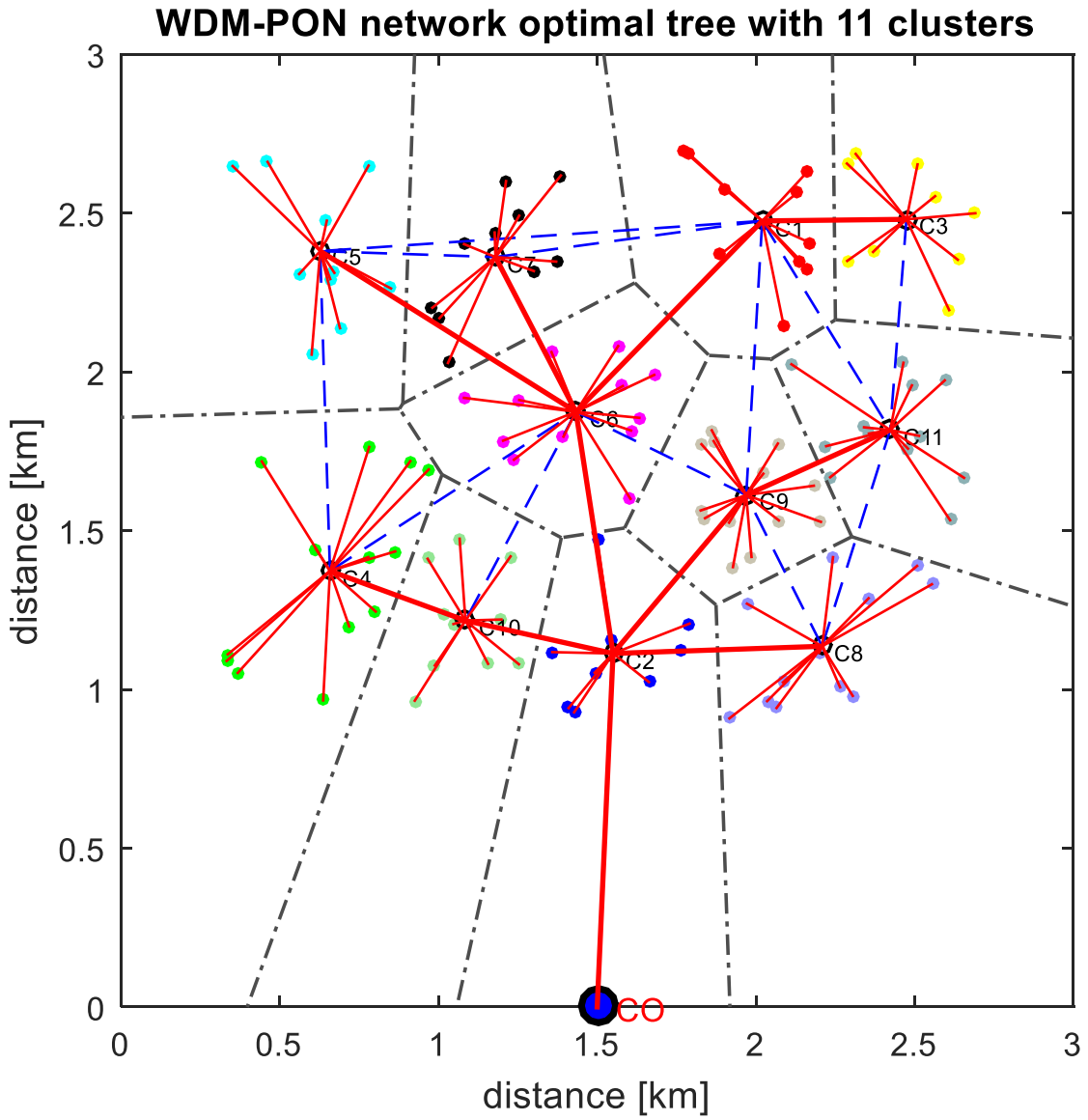


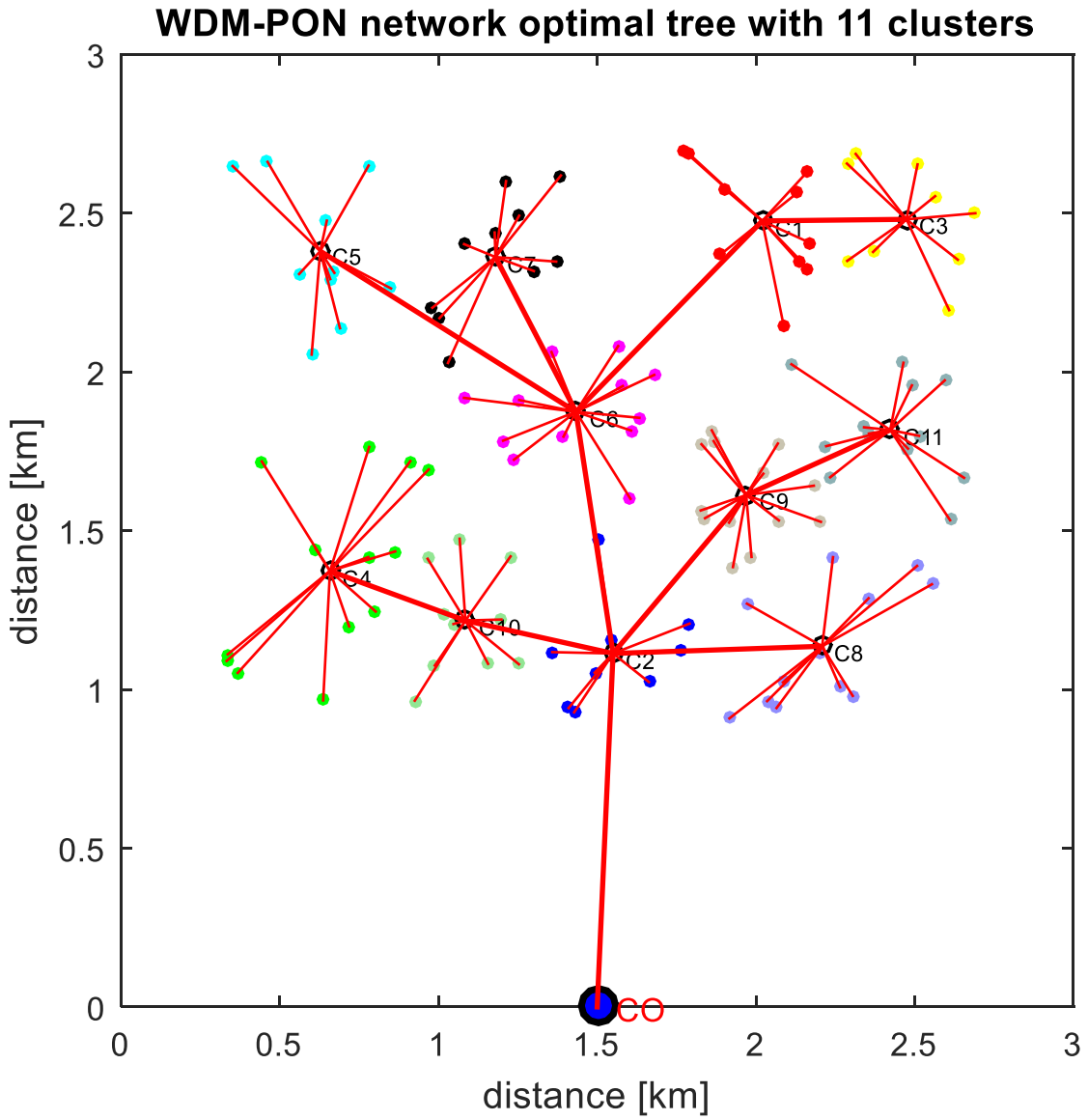
Algorithm description



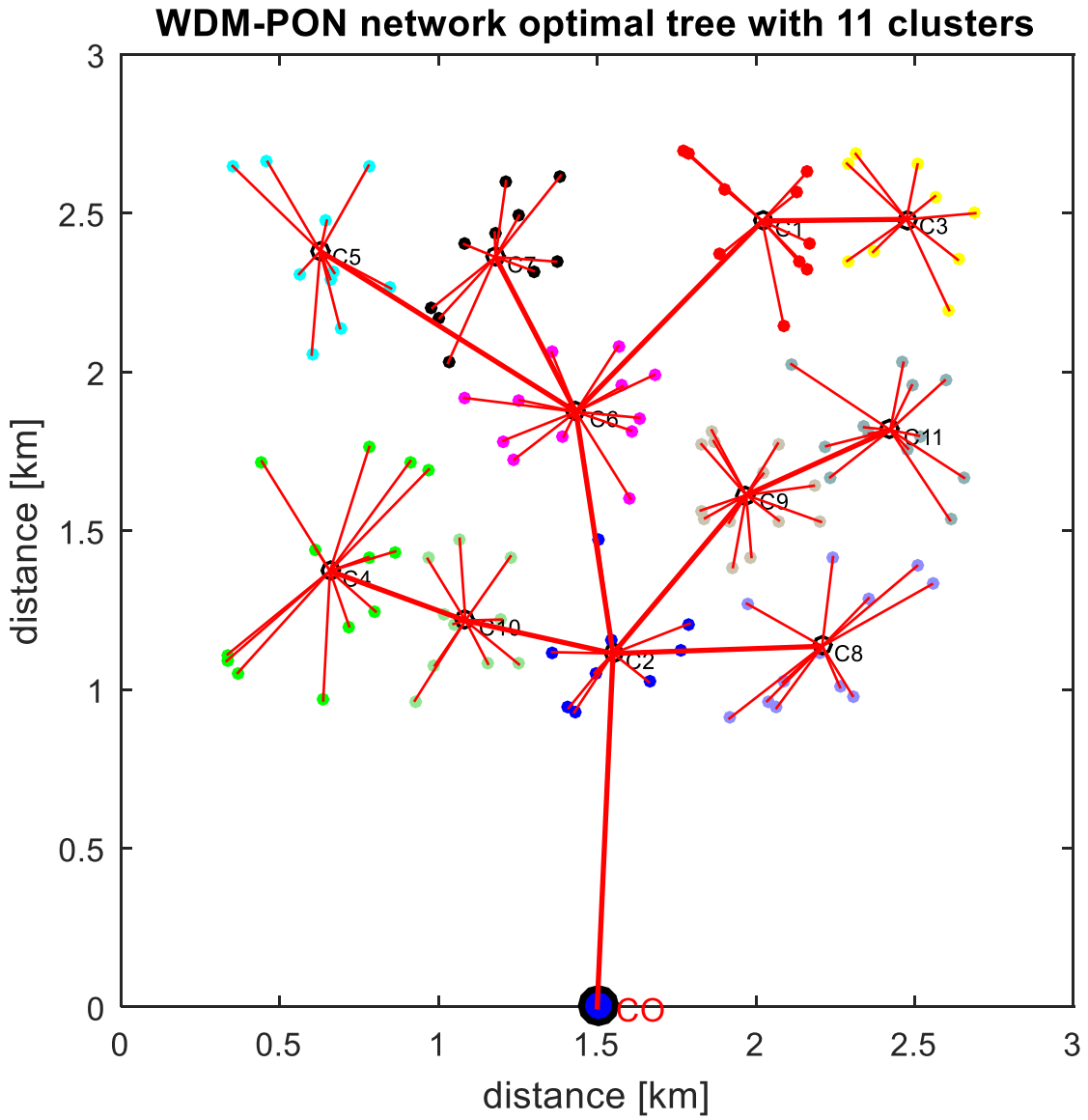
Algorithm description



Algorithm description



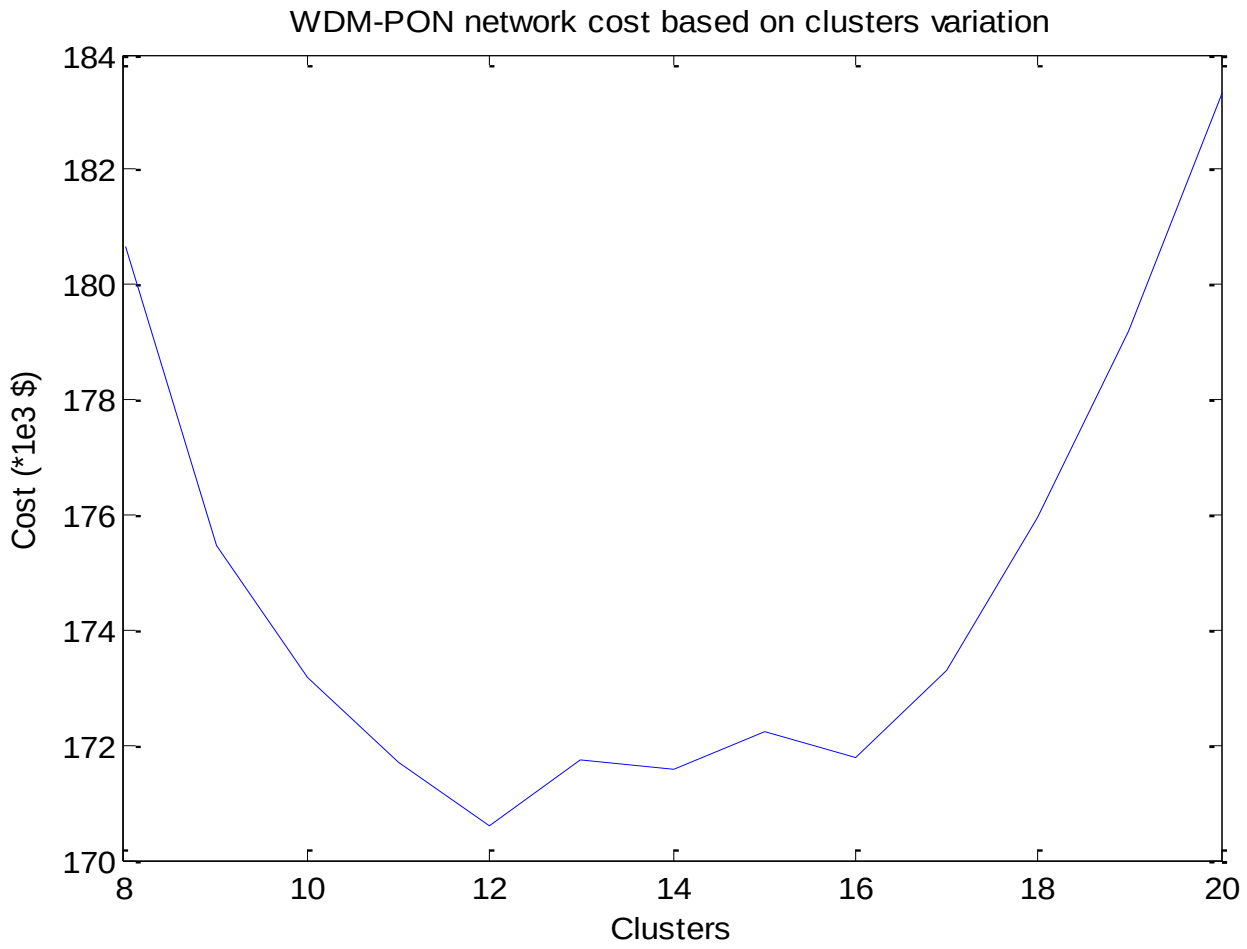
Algorithm description



Optimal topology for PON's deployment

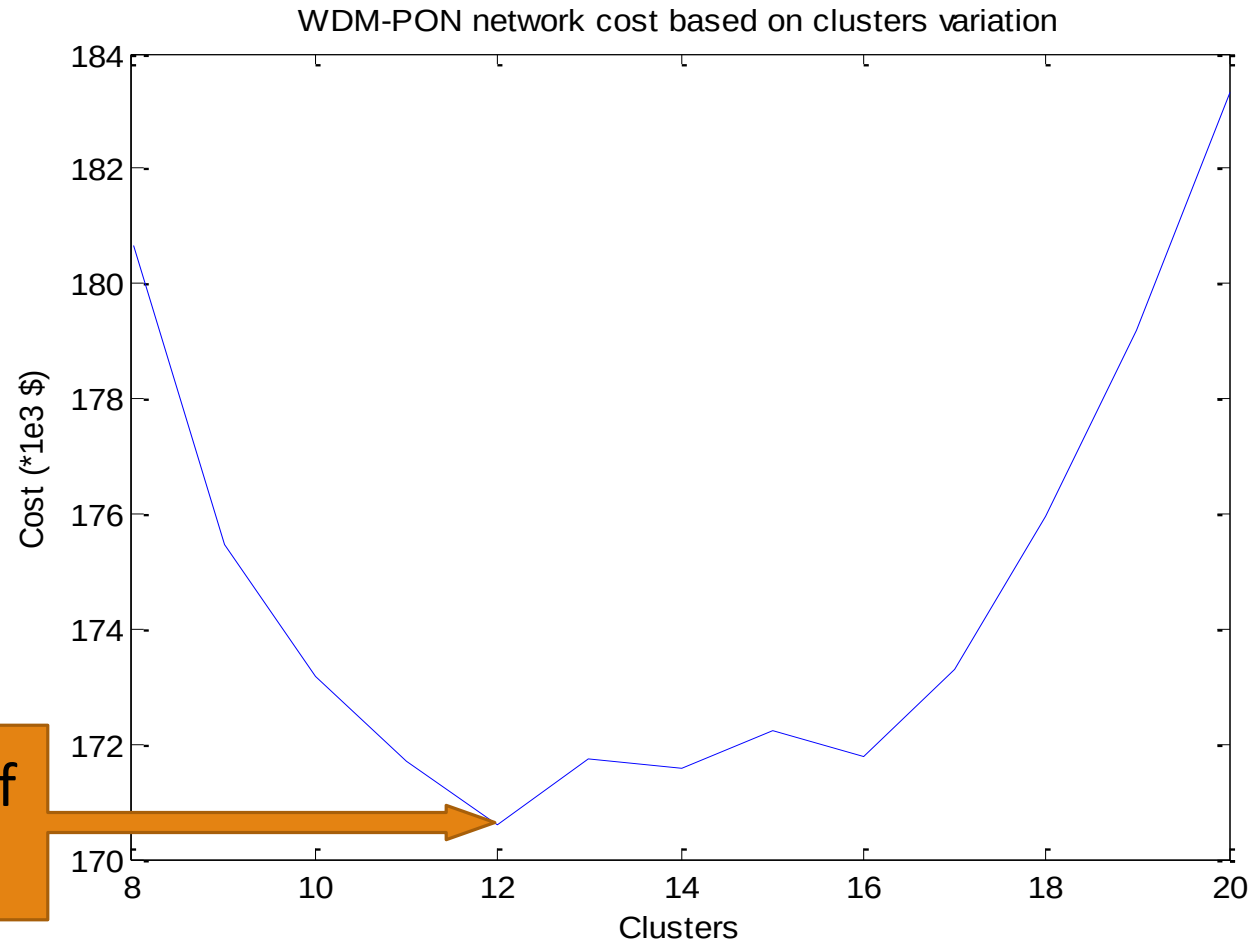
Algorithm description

Sweeping the clusters' number it can be find the optimal number of clusters for the PON deployment:



Algorithm description

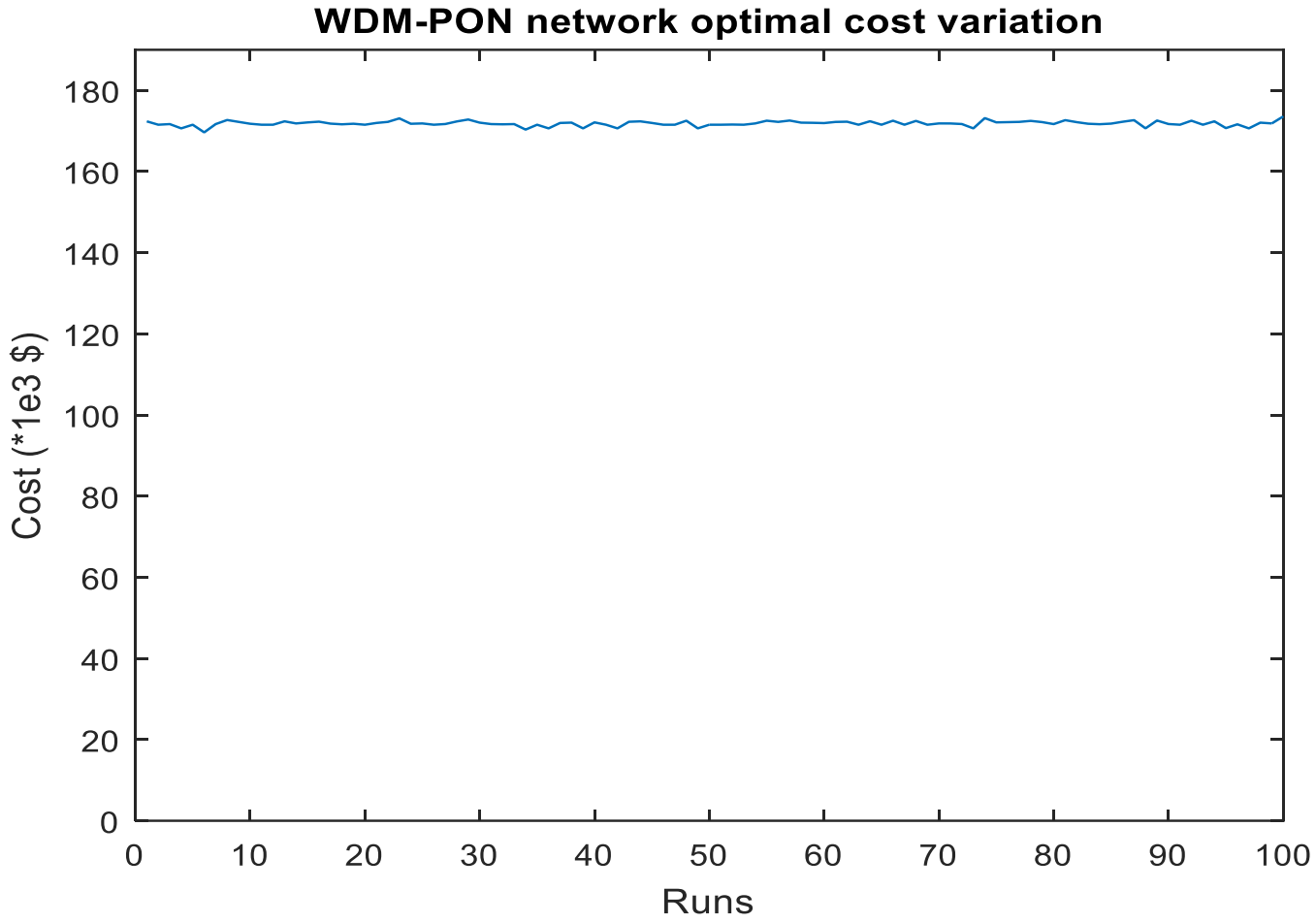
Sweeping the clusters' number it can be find the optimal number of clusters for the PON deployment:



Optimal number of clusters: 12

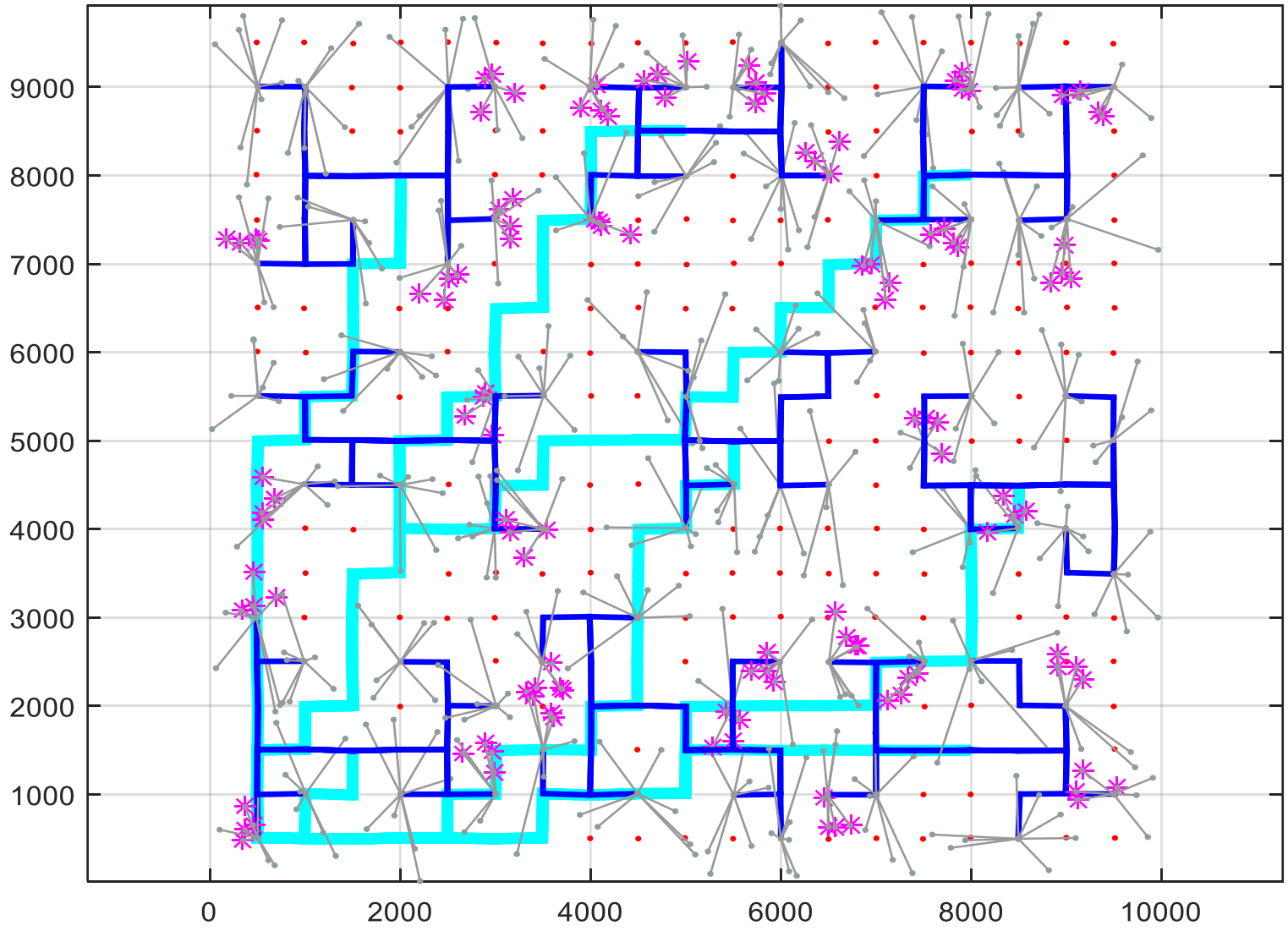
Algorithm description

The algorithm stability is around 1%



Algorithm description

This algorithm may be employed even for “street-aware” deployments, like a Manhattan-grid region:



Algorithm description

The algorithm previously described permit to find an optimal and feasible WDM PON topology for a randomly distributed users' region. The search based on the clusters' number variation permit to identify a feasible and optimal topology taking into account the optical fiber cost and the switching equipment cost.

The employment of the Delaunay triangulation in the users' region reduces de complexity of the minimum spanning tree search which permits the resolution of the problem in nearly linear time.

An opened problem to be resolved is the consideration of multiple next-generation PON deployment.

Publications

- G. V. Arévalo, R. C. Hincapié, and J. E. Sierra, “UDWDM-PON design model based on asymmetrical clustering, channel capacity and BER restrictions” in IEEE Latin-American Transactions Journal, 2015. (Article in press).
- G. V. Arévalo, R. C. Hincapié, and J. E. Sierra, “Optimization model for UDWDM-PON deployment based on physical restrictions and asymmetric users’ clustering,” in Proc. SPIE 9626, Optical Systems Design 2015: Optical Design and Engineering VI, 2015, vol. 9626, pp. 1–11.
- G. V. Arévalo, R. C. Hincapié, and J. E. Sierra, “WDM-PON Design Model based on the Minimum Spanning Tree search over Delaunay Triangulations,” IEEE Asia-Pacific Conf. Comput. Aided Syst. Eng., 2015.
- G. V. Arévalo, “Redes WDM PON: Tendencias y soluciones para viabilizar y optimizar su implementación,” Rev. Politécnica, vol. 35, no. 1, pp. 103 – 109, 2015.
- G. Arévalo, J. Sierra, and R. Hincapié, “ILP model for Greenfield WDM PON network design based on physical layer constraints.pdf,” in Proc. SPIE 8842, Novel Optical Systems Design and Optimization XVI, 88420F, 2013, vol. 8842, no. 0, pp. 1–6.

My work at POLITO-OPTCOM

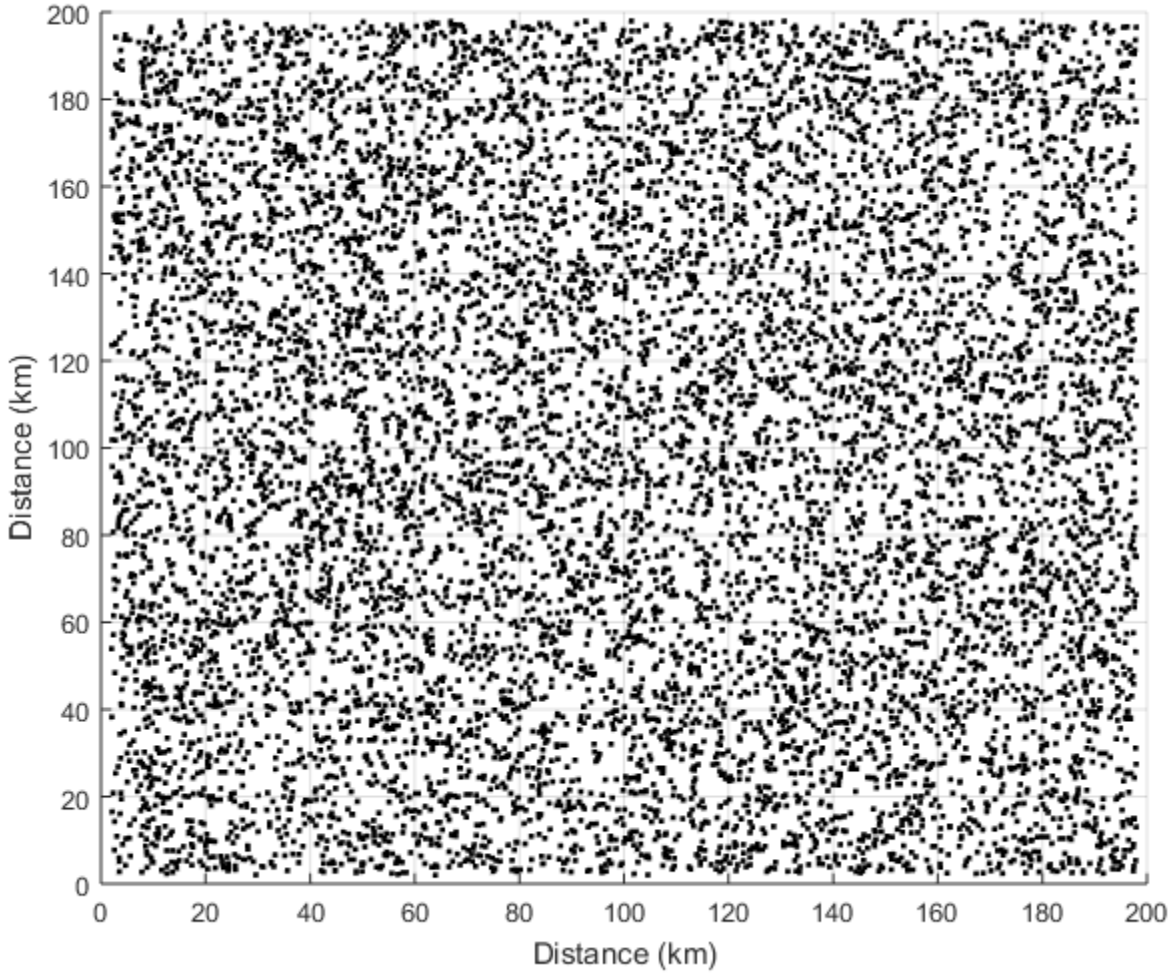
At POLITO-OPTCOM with the collaboration of Professor Roberto Gaudino I'm working on the "Optimization of multiple UDWDM-PON deployment based on physical restrictions and asymmetric users' clustering".

OBJECTIVES:

- To develop a cross-layer scheme for optimal multiple UDWDM PON topology planning taking into account a very large number of residential and corporative users (e.g. 10^5 users) with different bit rate demands.
- To evaluate of the model in order to characterize its performance and effectiveness comparing costs of UDWDM PON deployment with other standardized PON deployments like GPON, XGPON and NGPON2.

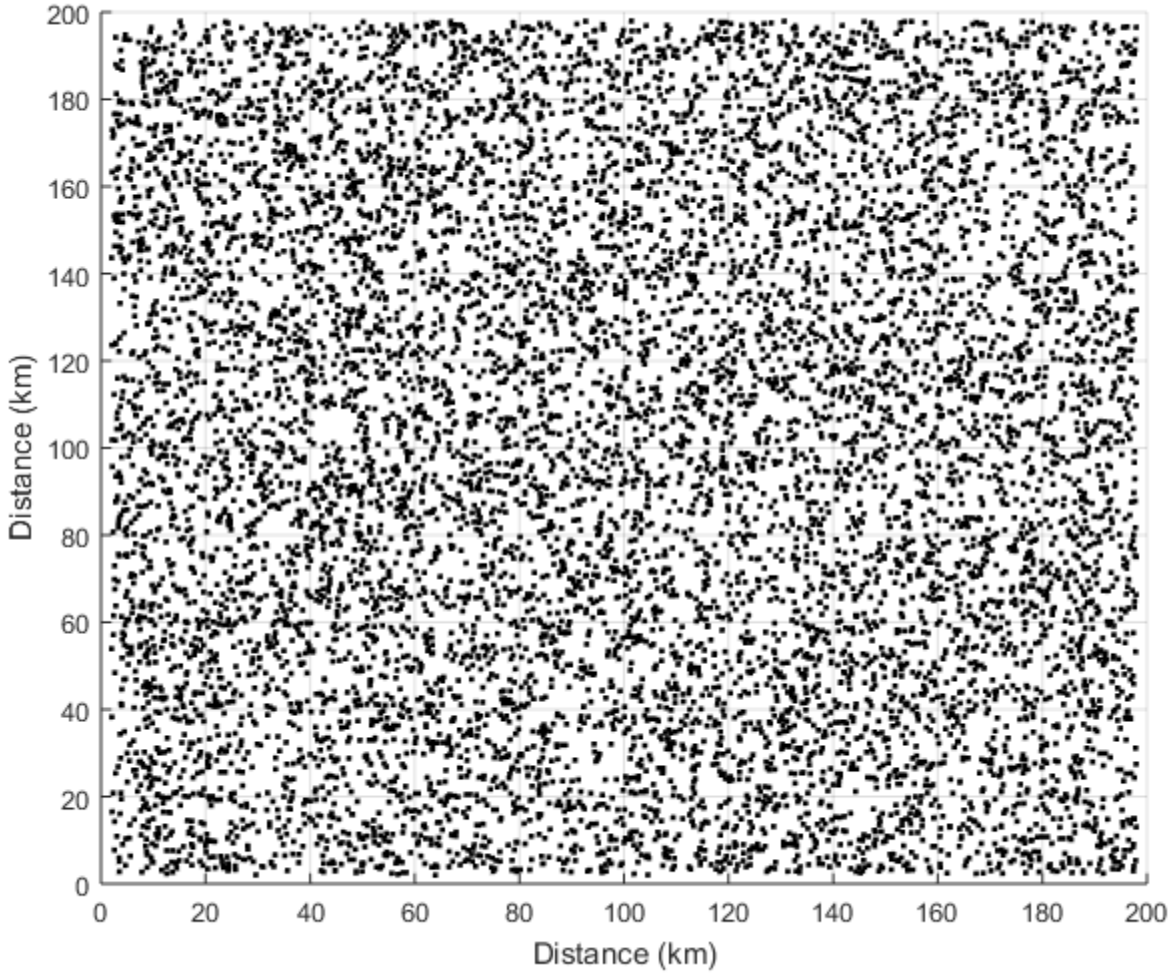
My work at OPTCOM

SCENARIO:



My work at OPTCOM

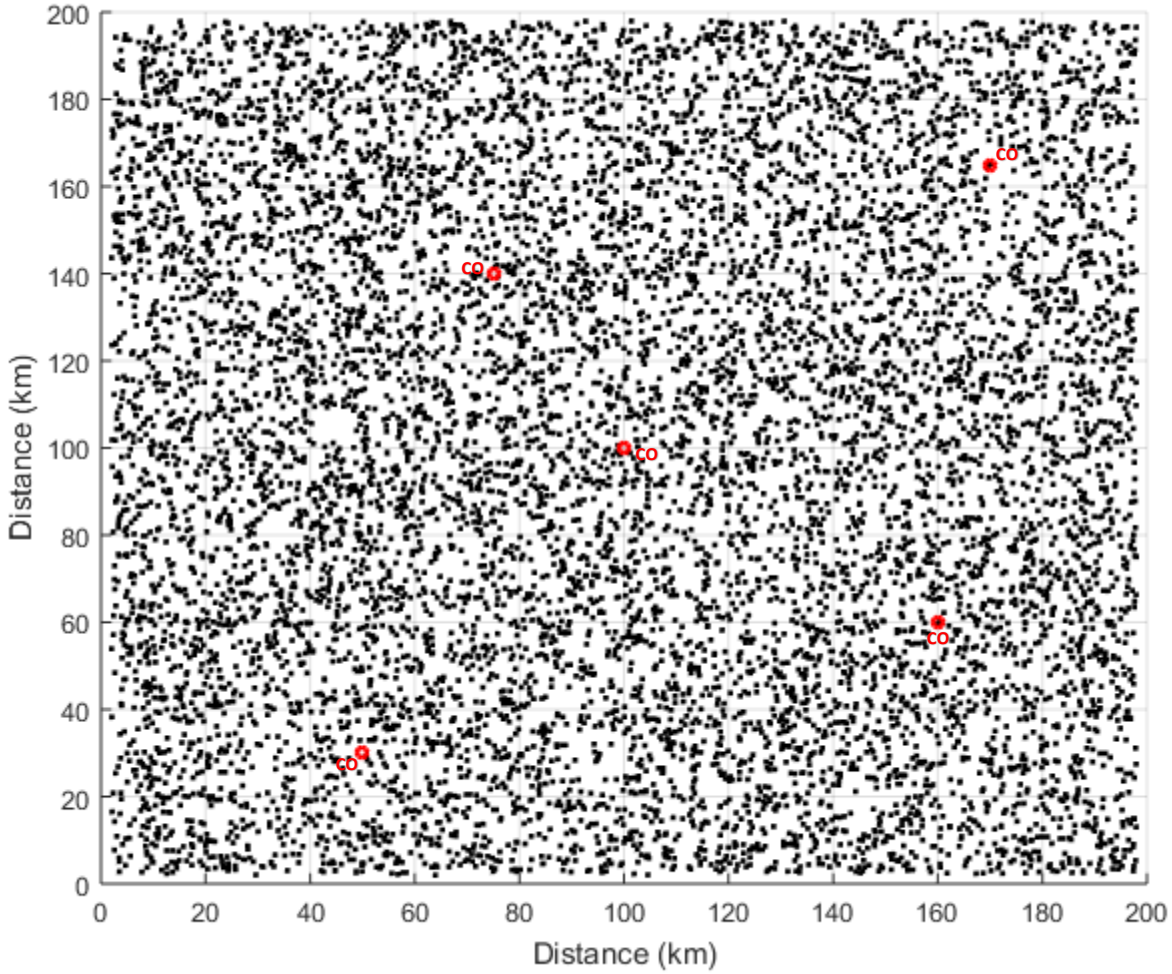
SCENARIO:



10^5 users

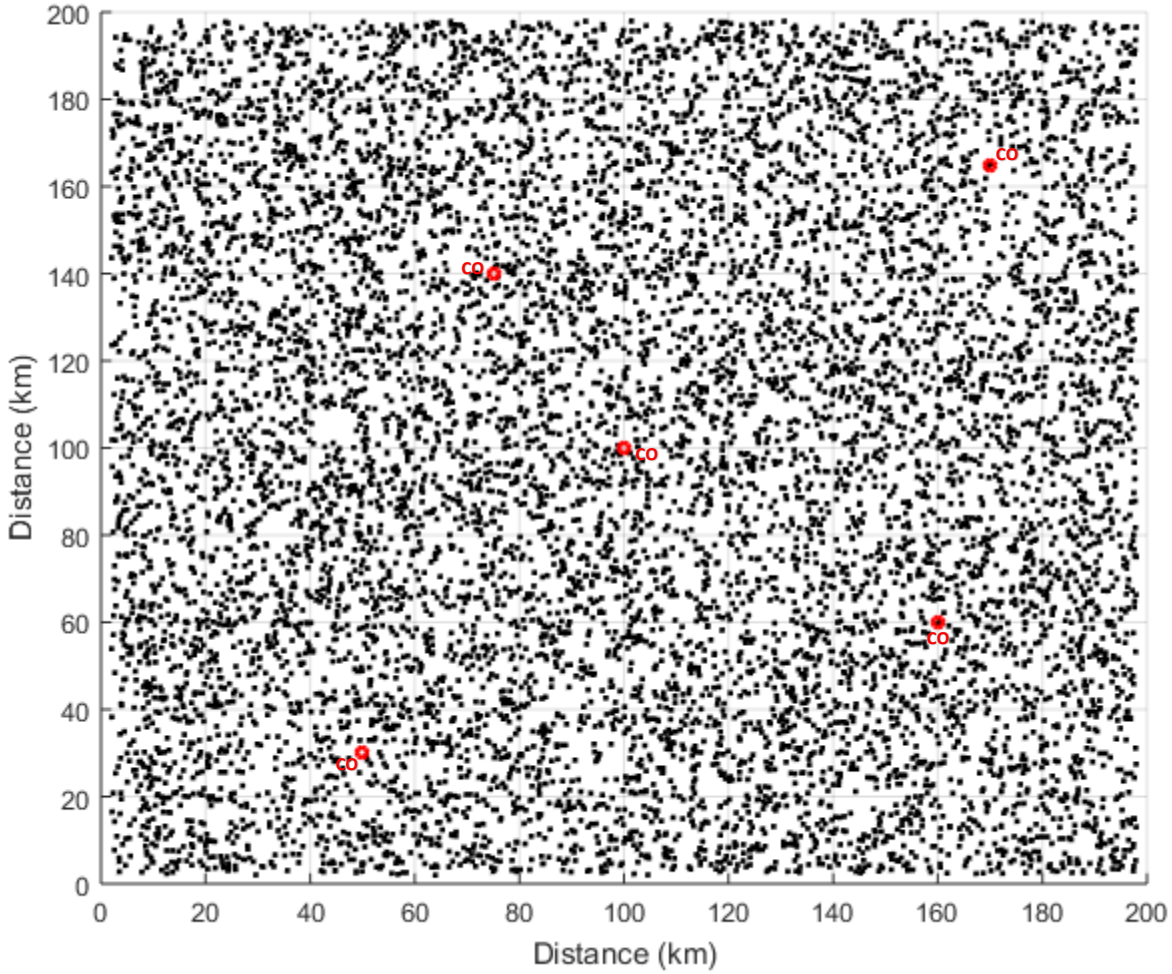
My work at OPTCOM

SCENARIO:



My work at OPTCOM

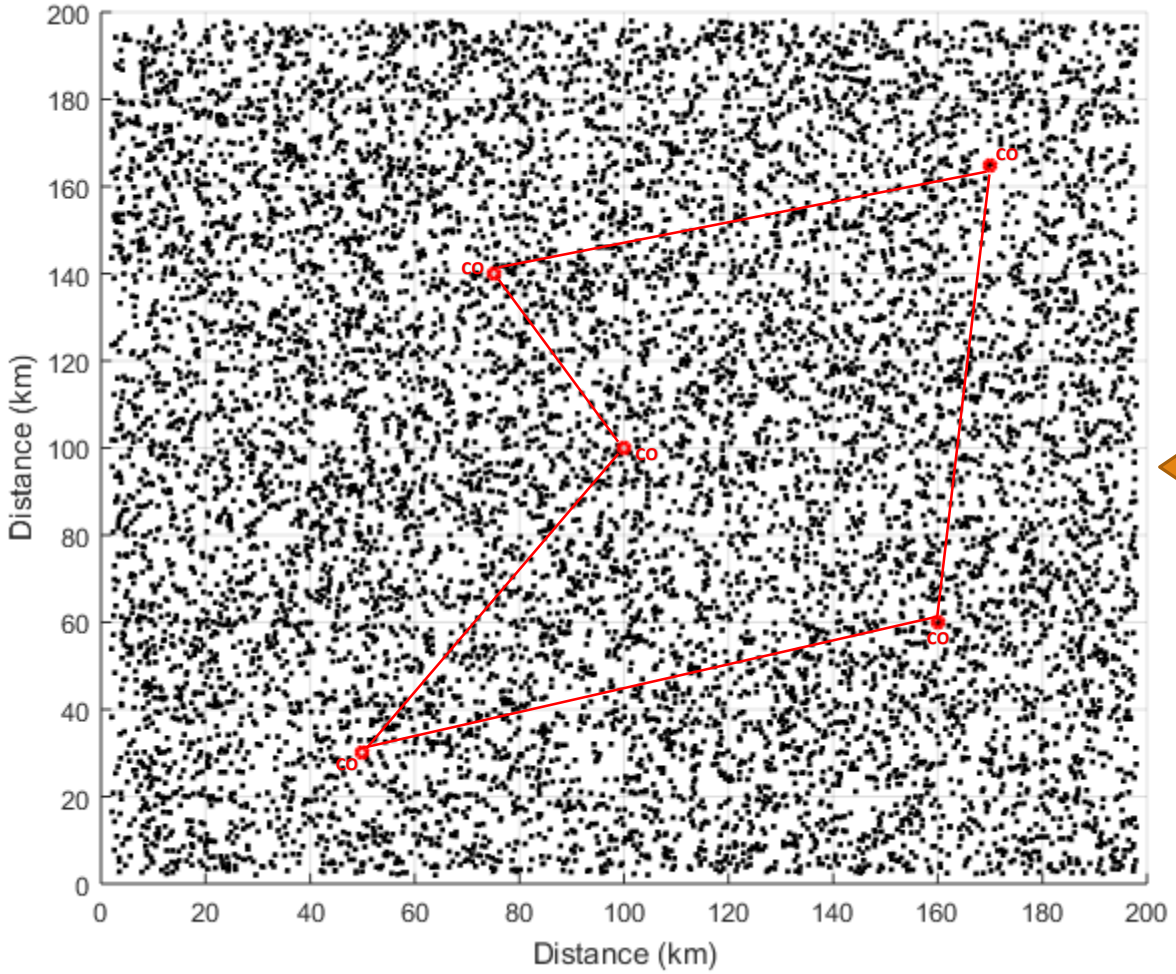
SCENARIO:



Many CO

My work at OPTCOM

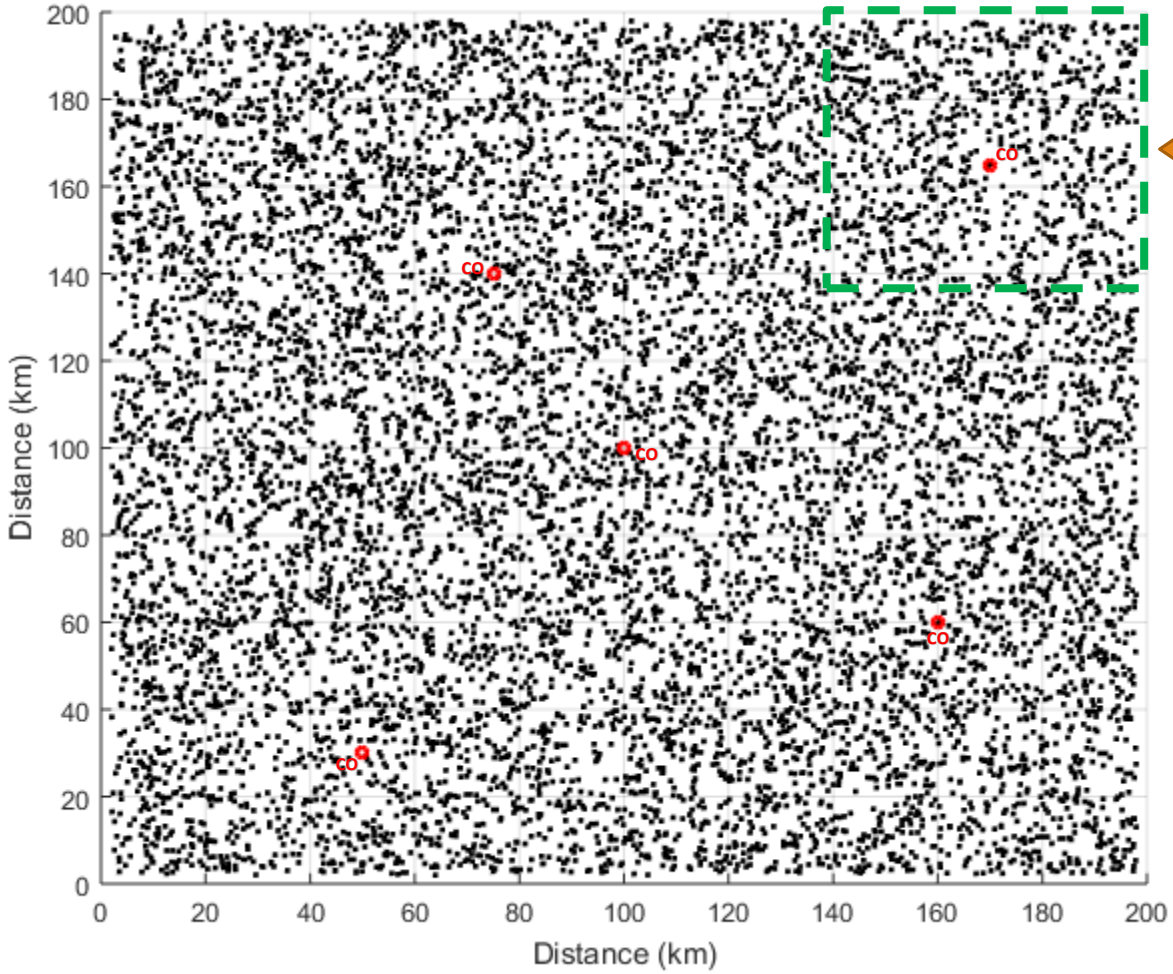
SCENARIO:



Interconnected

My work at OPTCOM

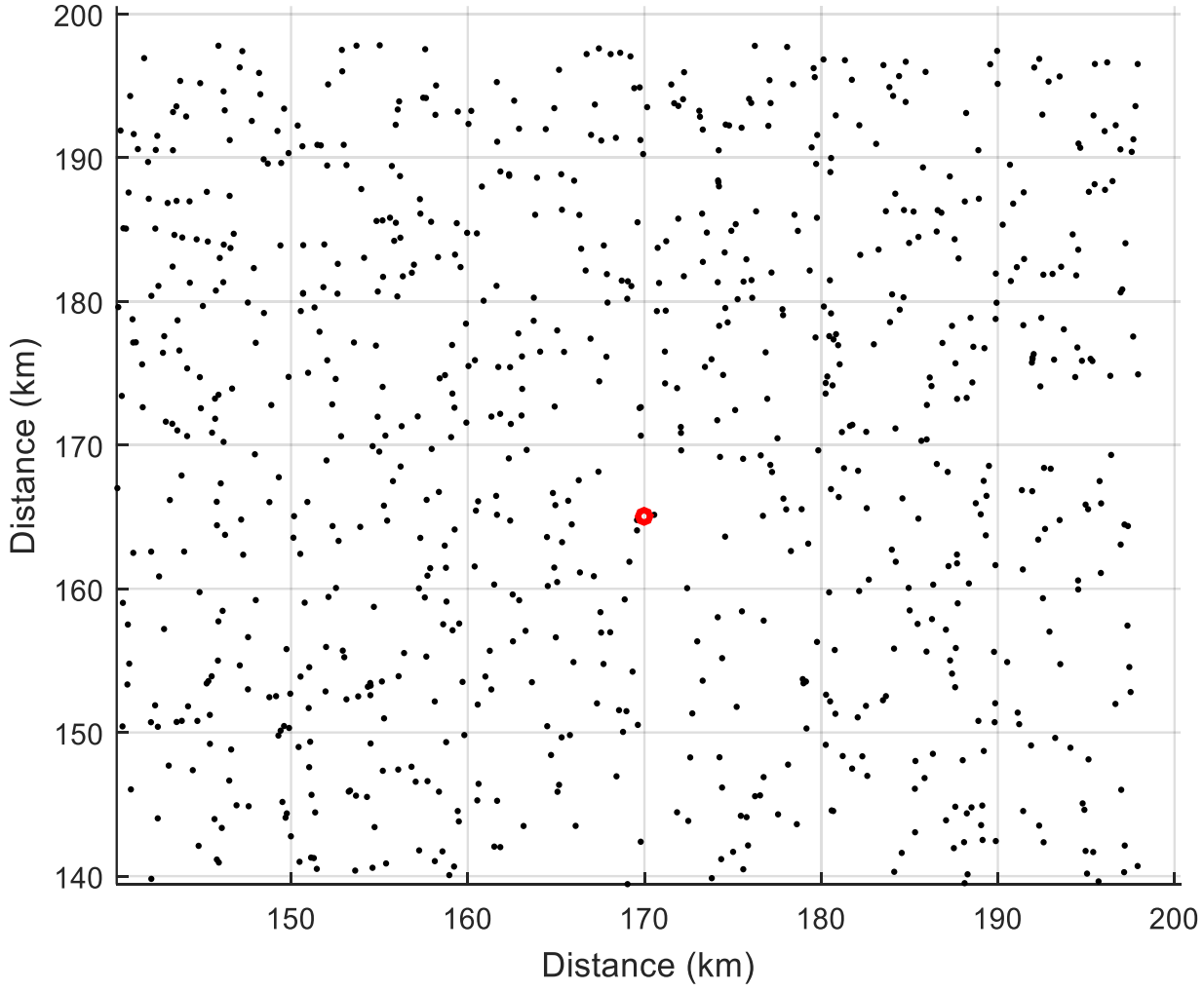
SCENARIO:



Lets' focus on a smaller region

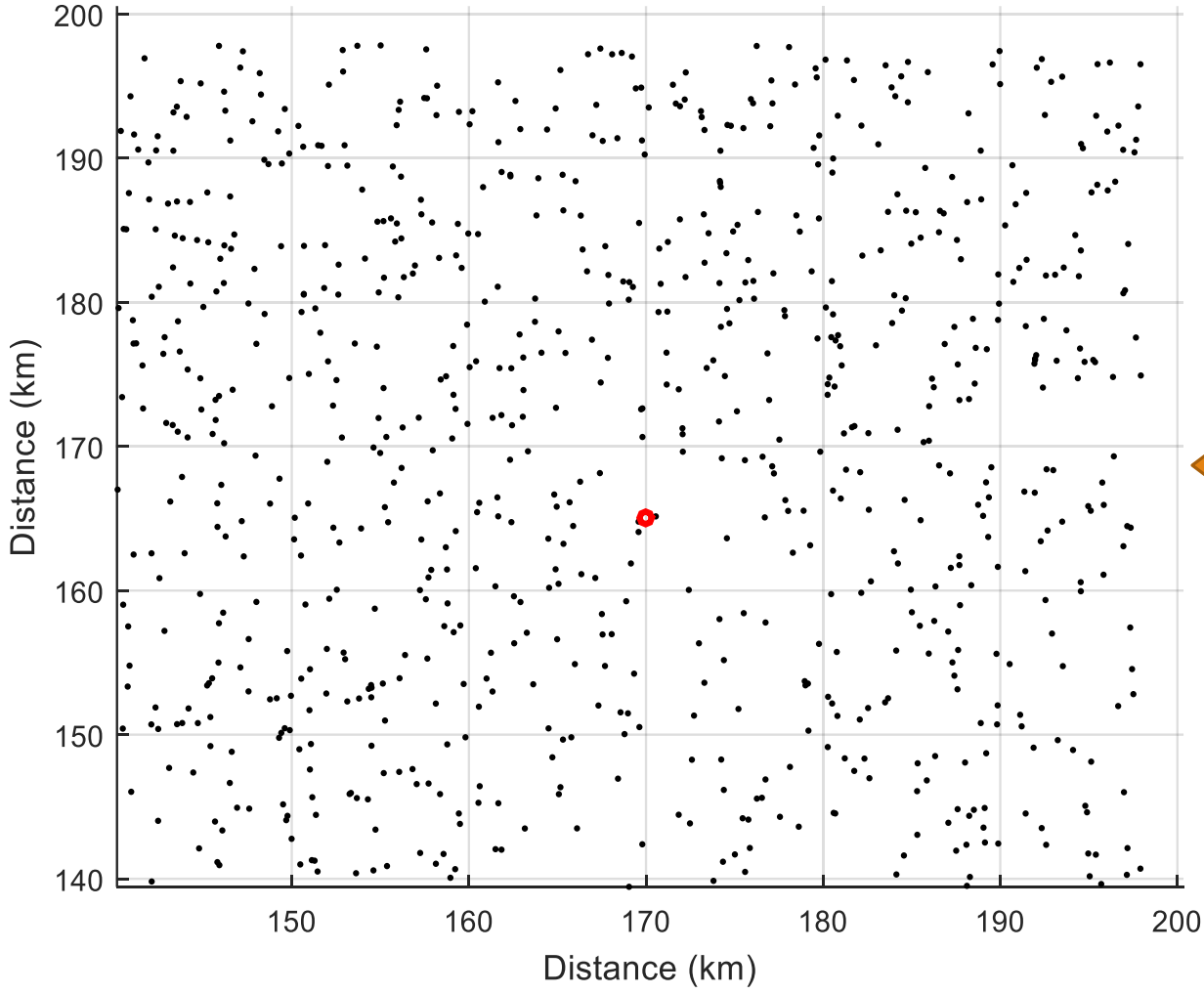
My work at OPTCOM

SCENARIO:



My work at OPTCOM

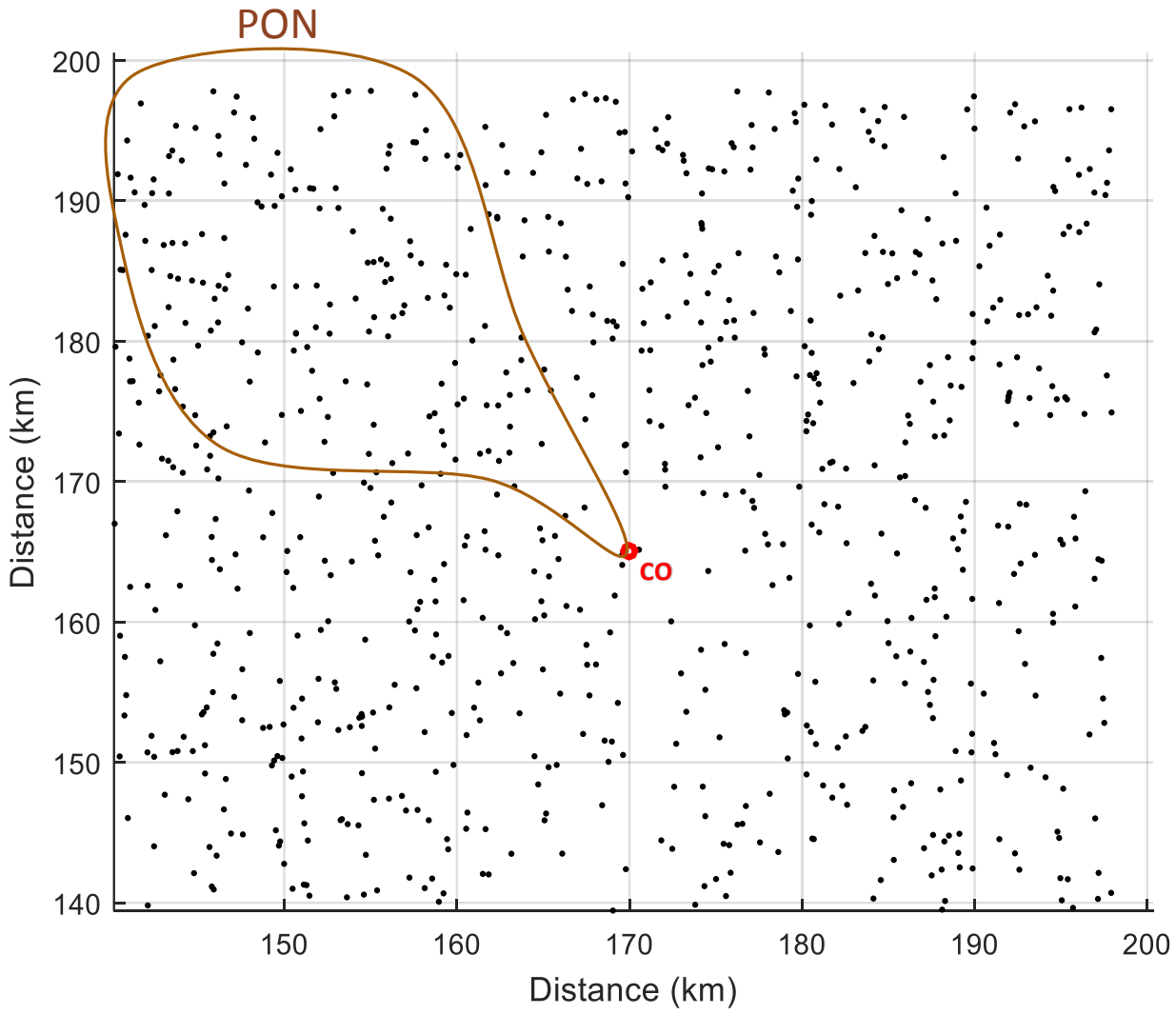
SCENARIO:



The only way of connecting so many users is through a multiple PON deployment

My work at OPTCOM

SCENARIO:



My work at OPTCOM

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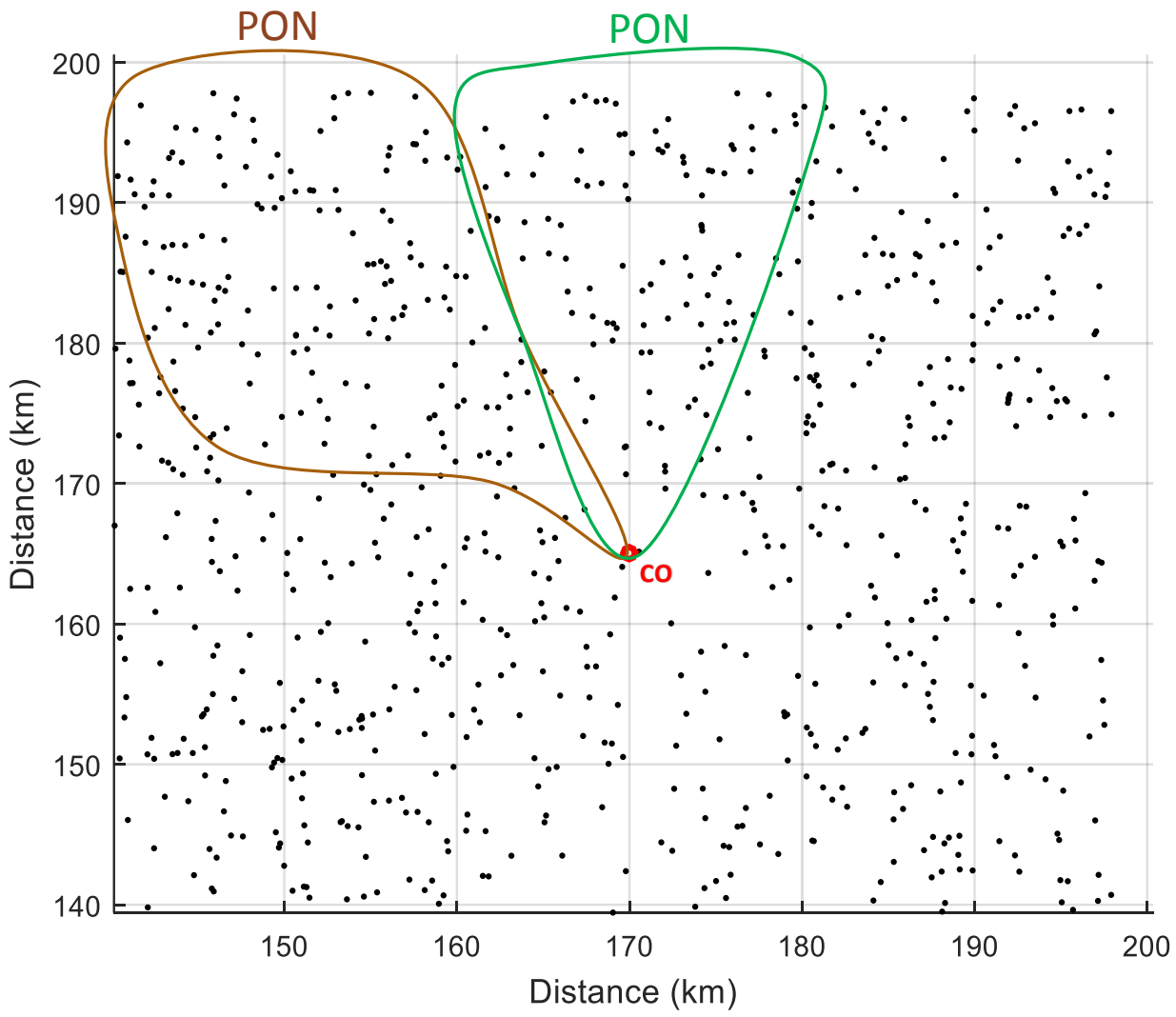

My work at OPTCOM

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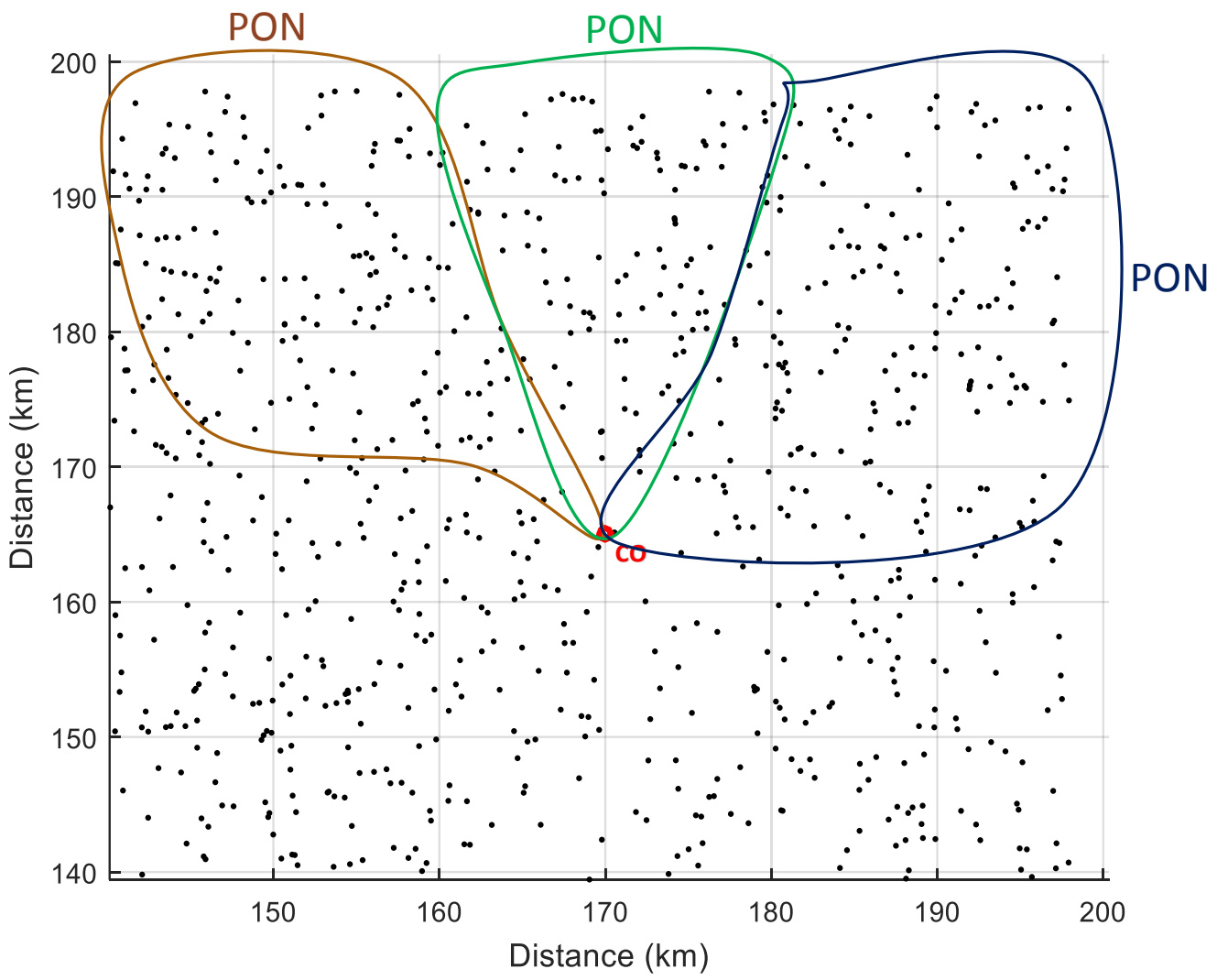

My work at OPTCOM

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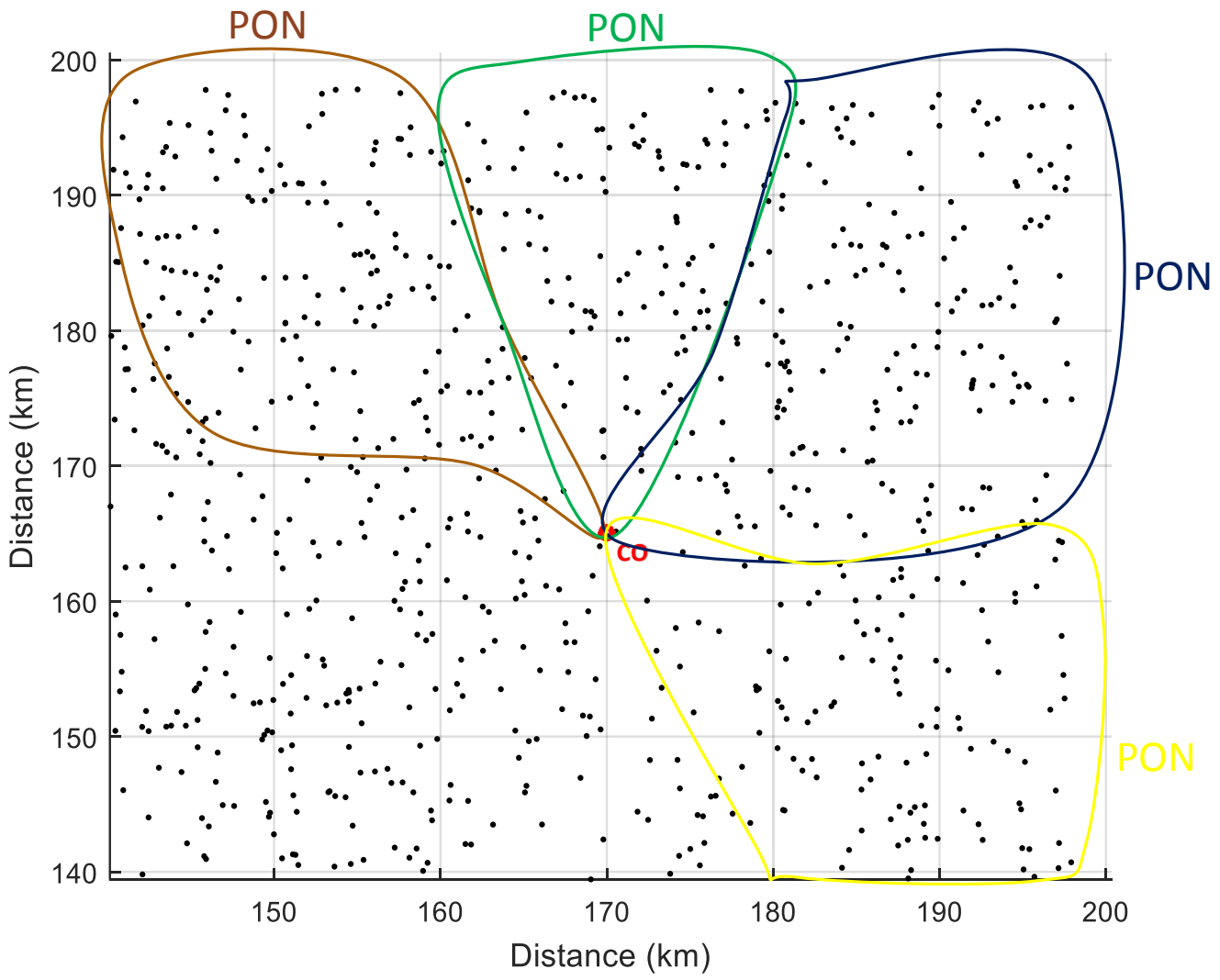

My work at OPTCOM

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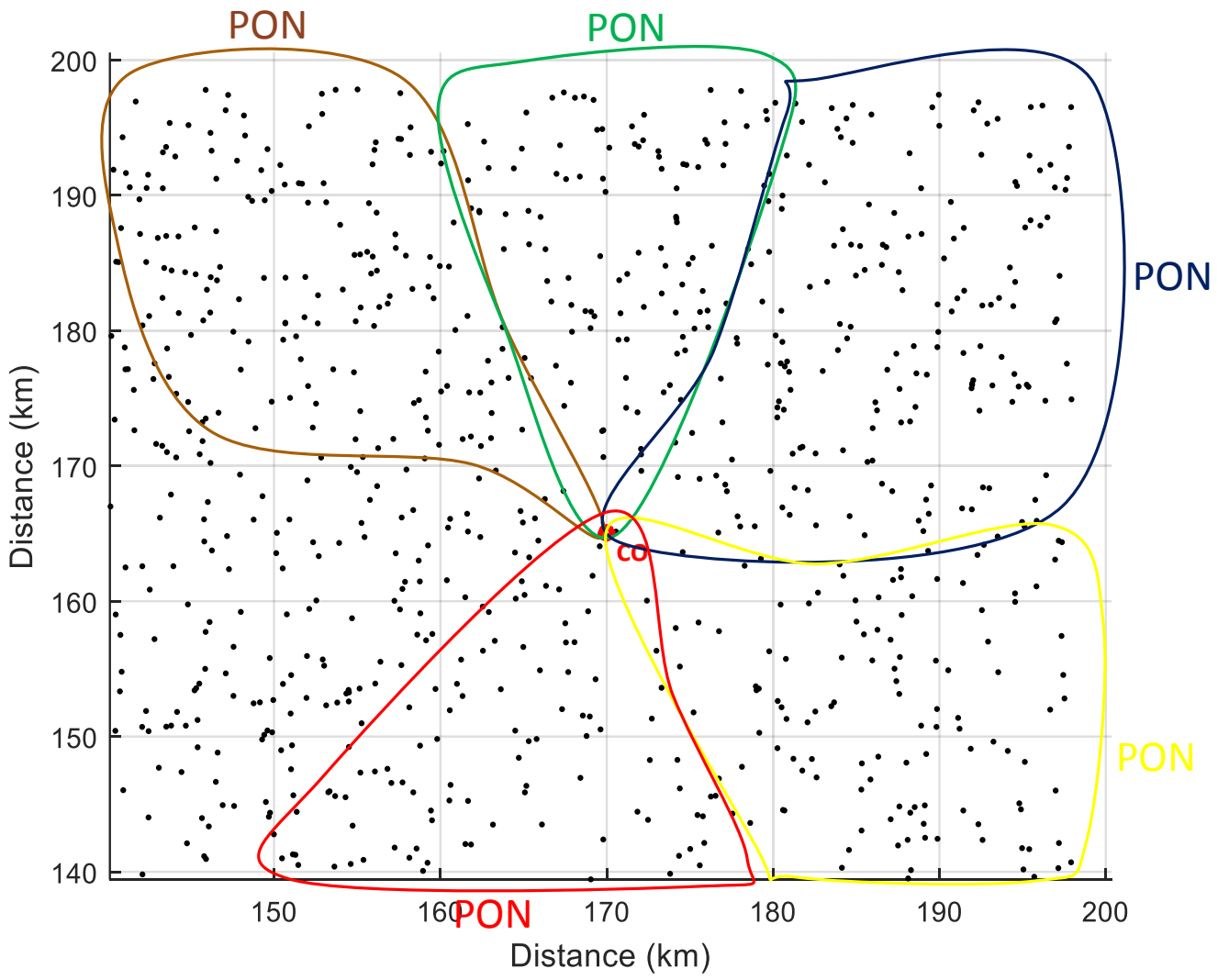

My work at OPTCOM

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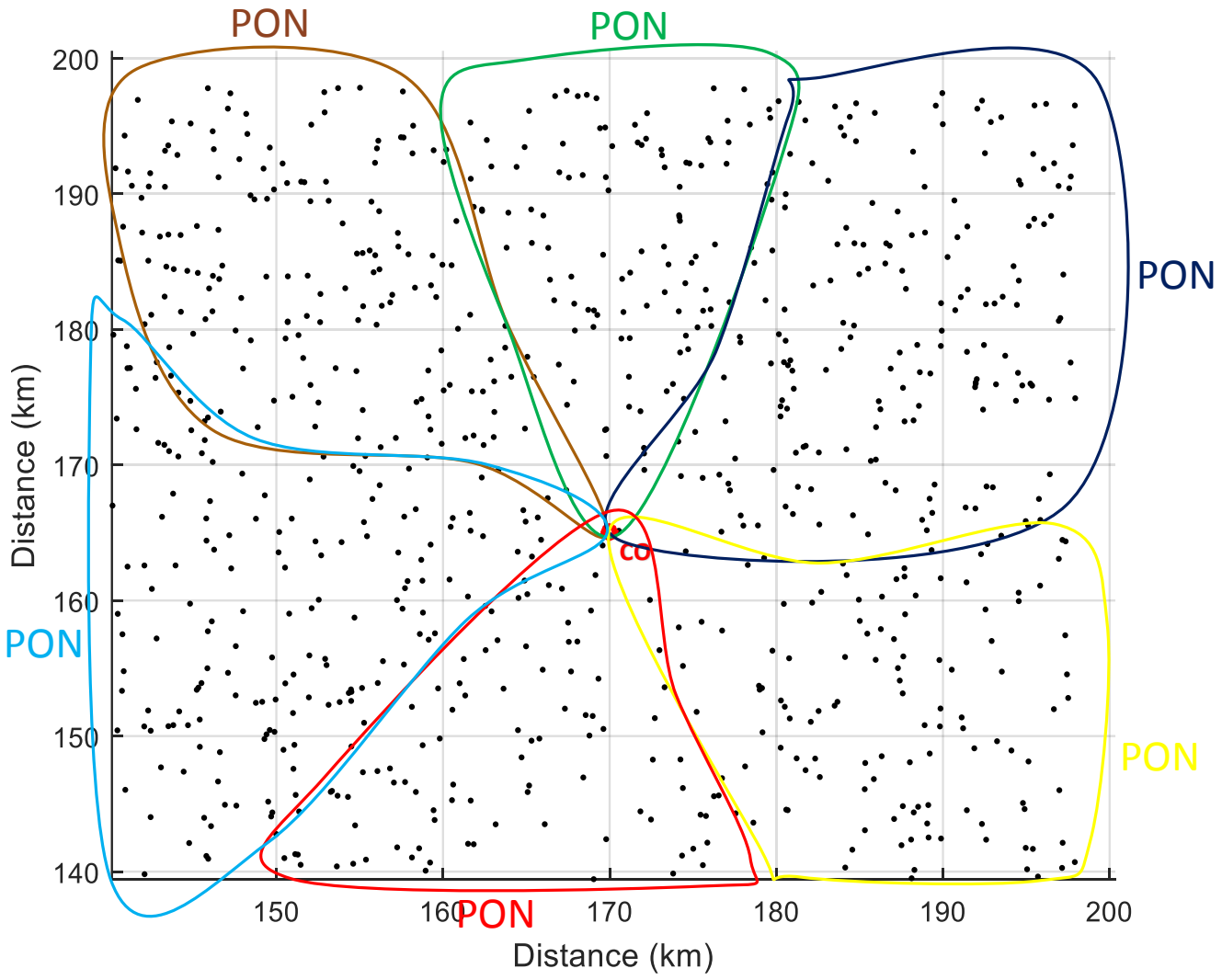

My work at OPTCOM

REFERENCE PARAMETERS:

PON capacity:

- GPON: US: 1.25 Gb/s; DS: 2.5 Gb/s (64 users and one wavelength per each OLT);
  - $US_{BR/\lambda}$ = 1.25 Gb/s ; $DS_{BR/\lambda}$ = 2.5 Gb/s
- XGPON: US: 2.5 Gb/s; DS: 10 Gb/s (64 users and one wavelength per each OLT);
  - $US_{BR/\lambda}$ = 2.5 Gb/s ; $DS_{BR/\lambda}$ = 10 Gb/s
- NGPON2: US: 10-40 Gb/s; DS: 40 Gb/s (64 users and four wavelengths per each OLT);
  - $US_{BR/\lambda}$ = 2.5-10 Gb/s ; $DS_{BR/\lambda}$ = 10 Gb/s
- UDWDM PON: 1 Gb/s US/DS per each user (256 users and 256 wavelengths per each OLT);
  - $US_{BR/\lambda}$ = $DS_{BR/\lambda}$ = 1 Gb/s

My work at OPTCOM

REFERENCE PARAMETERS:

Maximum links' length:

- GPON, XGPON, NGPON2: 40 km
- UDWDM PON: 100 km

Power Budget:

- GPON, XGPON, NGPON2: 29 dB
- UDWDM PON: 43 dB

Number of users: 10^5

Bit rate requirements:

- Residential: 100 - 400 Mb/s,
- Business: 400 Mb/s - 10 Gb/s

My work at OPTCOM

OPTIMIZATION PROBLEM:

Minimize:

$$\sum_{(i,j)\in\{E_{\mathrm{ov}},E_{\mathrm{vw}},E_{\mathrm{u}}\}} C_{FO}\, x_{i,j} d_{i,j} + \sum_{k,r,m,i\in\{O,V,W\}} \left(C_S^k s_i^k + C_{st}^R c_i^R\right) + \sum_{i\in U} C_{ONU} + \sum_{i\in U} C_{OLT}$$

Cost of optical fiber cable + installation

Cost of splitters and street cabinets

Cost of OLTs and ONUs (based on complexity)

My work at OPTCOM

OPTIMIZATION PROBLEM:

Minimize:

$$\sum_{(i,j)\in\{E_{ov},E_{vw},E_{u}\}} C_{FO}\, x_{i,j} d_{i,j} + \sum_{k,r,m,i\in\{O,V,W\}} \left(C_S^k s_i^k + C_{st}^R c_i^R\right) + \sum_{i\in U} C_{ONU} + \sum_{i\in U} C_{OLT}$$

Cost of optical fiber cable + installation

Cost of splitters and street cabinets

Cost of OLTs and ONUs (based on complexity)

Subject to some properly defined restrictions

THANKS FOR YOUR ATTENTION