Geometry-Based Optimization Heuristics for Region Coverage and Pathfinding in Drone-Based Operations

Kemal İhsan Kılıç and Leonardo Mostarda (Supervisor)

{kemal.kemal, leonardo.mostarda}@unicam.it

Computer Science Division, University of Camerino

Methods and Results

Region Coverage

Region Coverage is a special "Set Cover" ($\mathcal{NP}$-Hard) problem. We proposed multi-party multi-objective priority-based heuristic optimization based on EAs that can approximate solutions quickly to overcome complex formulation (for optimization) and "$\mathcal{NP}$-Hardness" [1,2].

Region coverage: Simulations Summary

EA	Soln Type	Best for
DEoptim	Population	Run time
GA	Population	Σ of drone dist. (energy)
GenSA	Single soln	Coverage

Boat Rescue: CS Grid and Pathfinding

We proposed optimum (min number and "no blind spot") CS grid configurations (Tri/Sq) to cover the operation region. The CS grid not only increases the operational range of the drone but also creates synergy with the proposed heuristic pathfinding algorithm, redGraySP, which "saves path length" in the range of 10-17% over the "base case". Proposed novel concave hull based TSP heuristic algorithm, concaveTSP, achieved approximation ratio of less than 1.5 for the datasets varying from 50 up to 30000 vertices [3,4,5].

Pathfinding: Simulations Summary

Type	Metric	Tri Grid	Sq Grid
Theoretical SingleBoat	**Prob. of having a Good RG Path**	0.78	0.82
	Prob. of using a Good RG Path	0.45	0.31
	Savings 1-way	43%	64%
	Savings return	20%	50%
	Area per CS	1.30 $unit^{2\dagger}$	0.5 $unit^2$
Simulations MultiBoat	**Tour Cost**	Higher	Lower
	***Tour Cost Savings%**	Higher	Lower
	AWD	Higher	Lower
	***AWD Savings%**	Higher	Lower
	Chargings	Not much difference	Not much difference
	***Chargings Savings%**	Higher	Lower
	***Number of CSs**	Lower (24)	Higher (30)

† 1 unit = Drone range

Tri gives better "relative" savings and better coverage, but the "tour" is more expensive.

Contributions

Region Coverage

- Novel and essential objectives for the coverage: **Overflow, overlap, sum of drone distances (energy).**
- Performance improvement: **Circle Packing** algorithm for the initial solutions to EAs.
- **Scenario-based weighted scoring** for the fitness function.
- **Multi BS** coverage framework for **Voronoi Tessellated region**, utilization of homogeneous/heterogeneous BSs.

Boat Rescue: CS Grid and Pathfinding

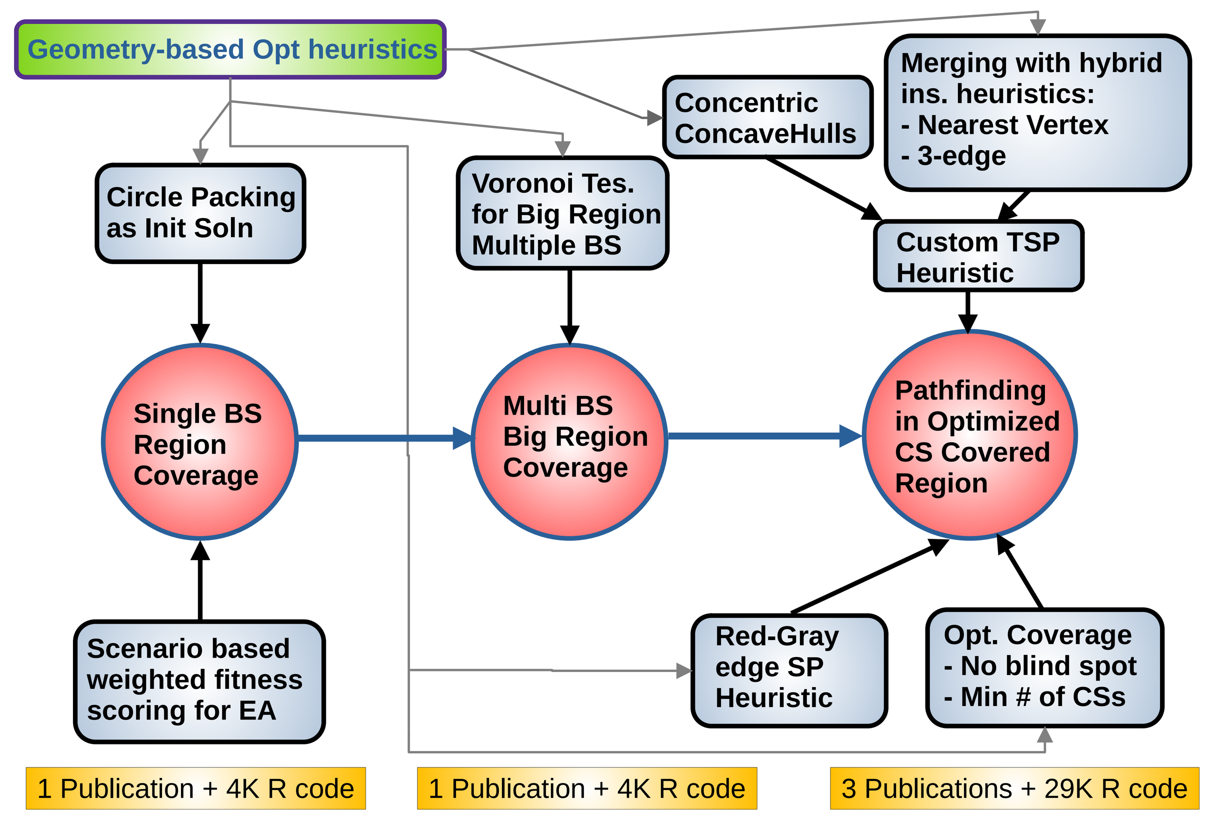
- **Static optimal (min CS - no blind spot) CS Grid** adjusted to drone range for complete region coverage.
- Novel **Coverage Effectiveness** metric for CS Grid.
- **Custom TSP (concaveTSP) + redGraySP pathfinding heuristics**.

Research Summary

Drones are versatile and can be used as mobile IoT platforms. However, the limited onboard energy requires optimization to increase operational effectiveness.

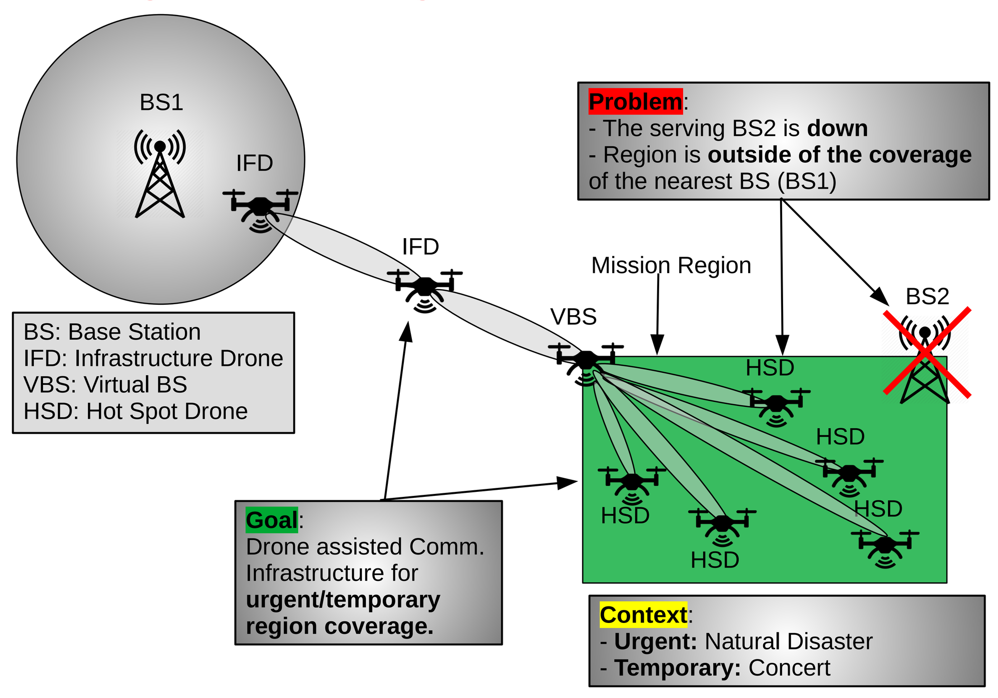
Static Operation: Region coverage is vital for communication in natural disasters or temporal events.

Dynamic Operation: Rescue operations require "region coverage" with CSs for the "reachability" of the drones. The "optimum" rescue path should be found quickly.

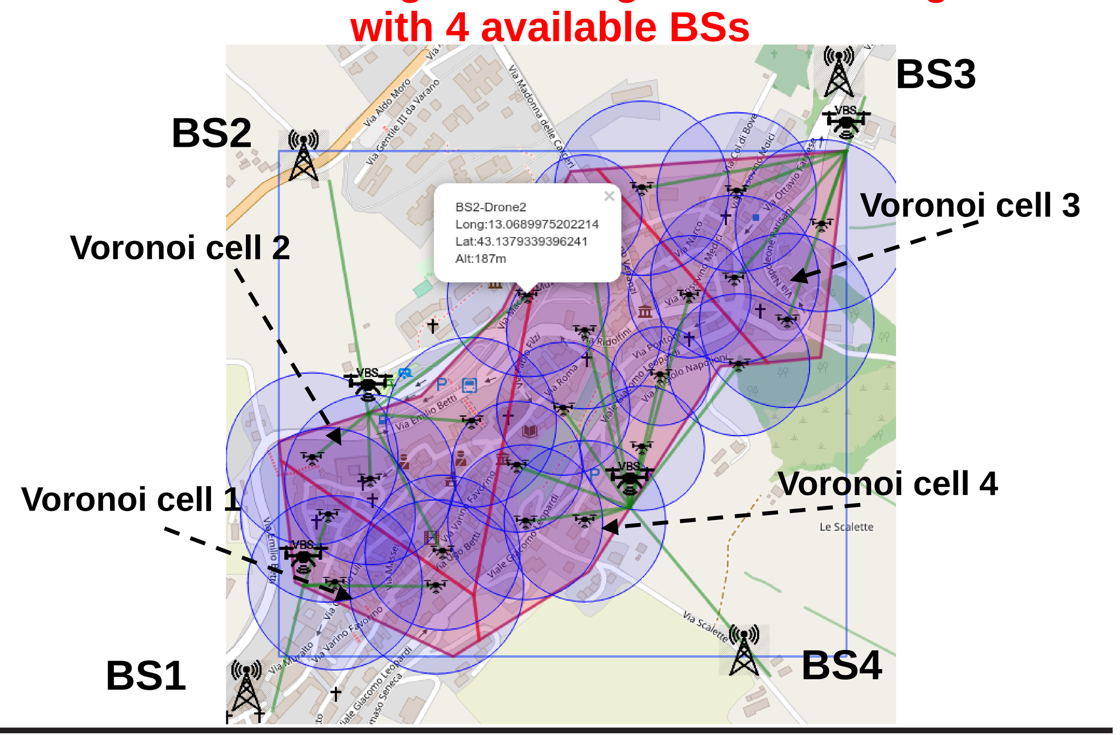


We proposed a flexible Evolutionary Algorithm (EA) based multi-party multi-objective optimization scheme for **single/multi-BS disaster region communication coverage** (first row) and a framework for **optimized heuristic drone pathfinding over an optimized charging station grid** for "visiting" entities in a "covered region" (second and bottom row).

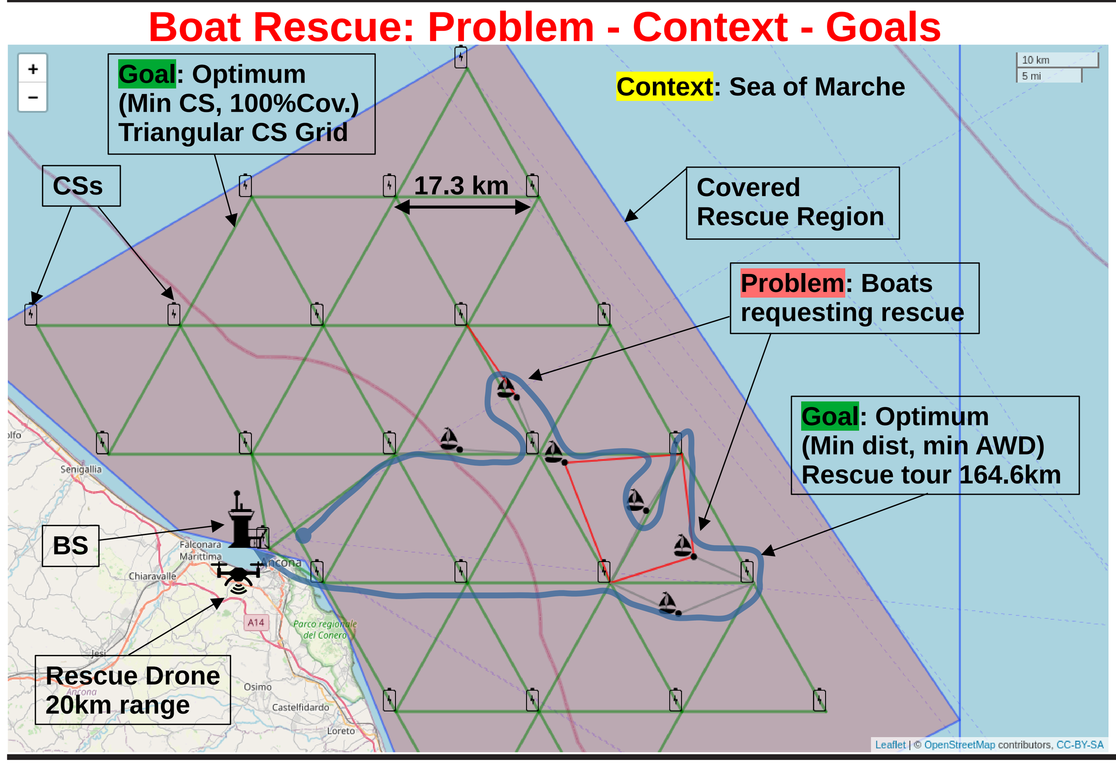
SingleBS Coverage: Problem - Context - Goals



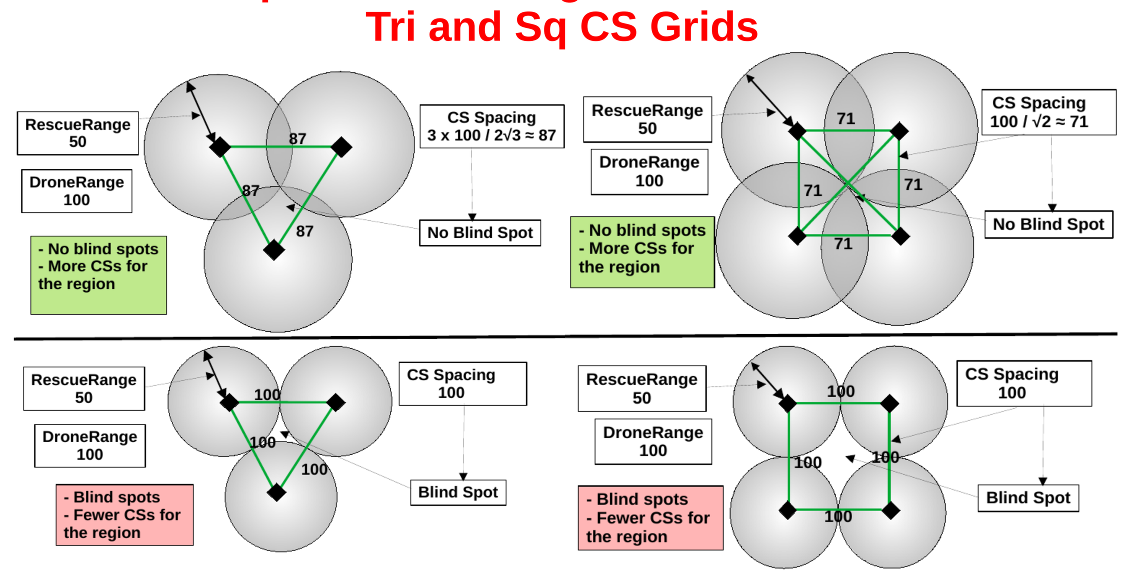
MultiBS Coverage: Coverage of divided region with 4 available BSs



Boat Rescue: Problem - Context - Goals

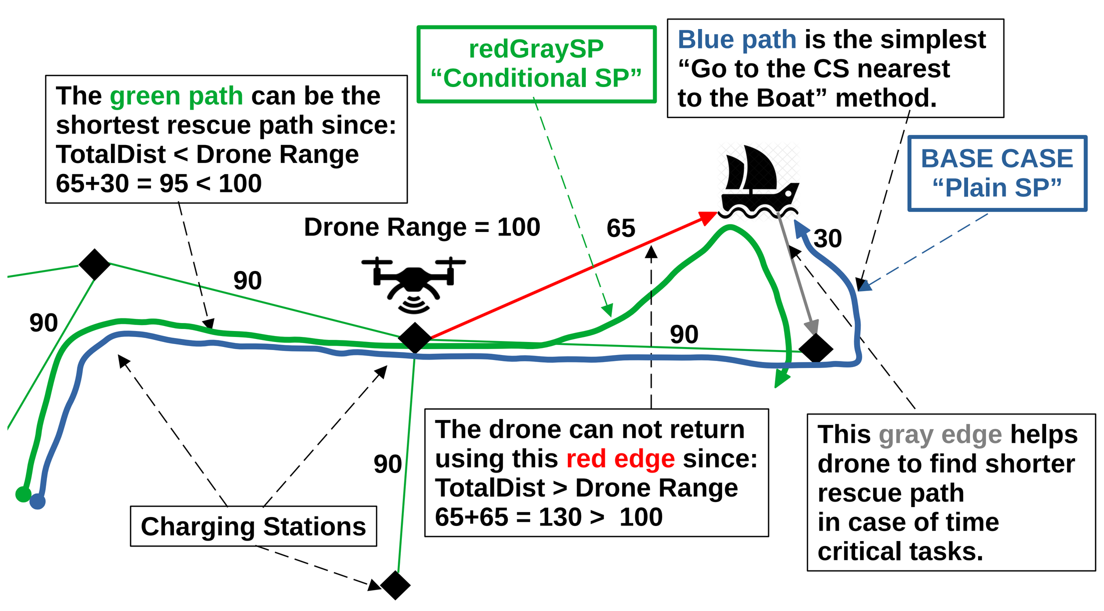


Optimum coverage conditions for Tri and Sq CS Grids

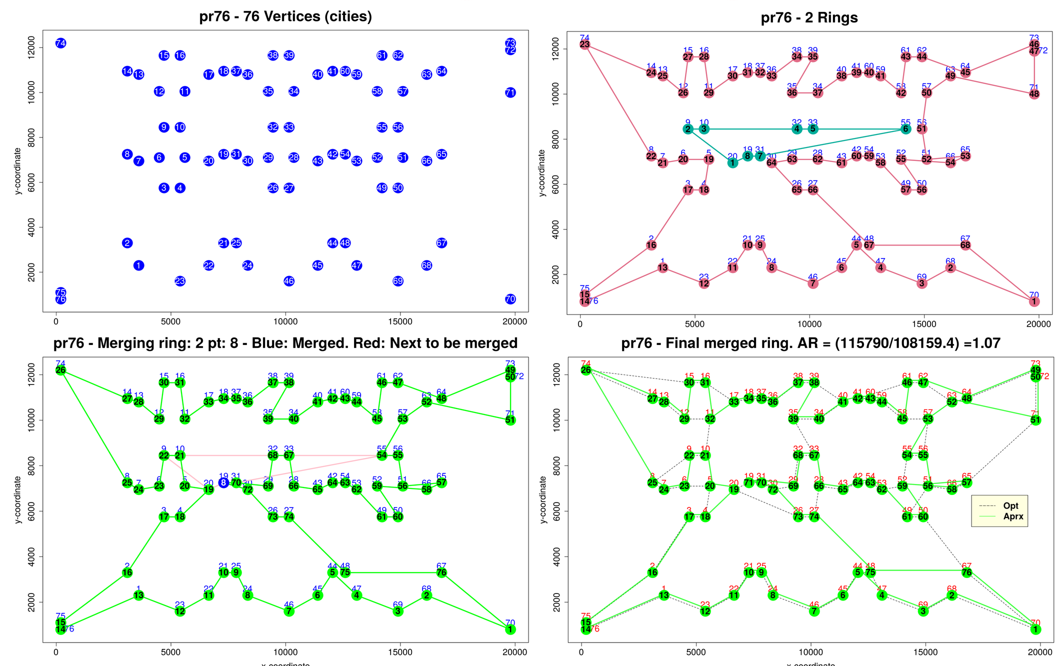


Min number CS - no blind spot region coverage

Heuristic idea used for redGraySP



ConcaveTSP: Stages for finding TSP tour



References

[1] K. I. Kilic, O. Gemikonakli, and L. Mostarda. Multi-objective Priority Based Heuristic Optimization for Region Coverage with UAVs. In AINA, Advances in Intelligent Systems and Computing, 1151:768–779. Springer, 2020.

[2] K. I. Kilic, O. Gemikonakli, and L. Mostarda. Voronoi Tesselation-based load-balanced multi-objective priority-based heuristic optimisation for multi-cell region coverage with UAVs. Int. Journal of Web and Grid Services, 17(2):152–178, 2021.

[3] K. I. Kilic and L. Mostarda. K. I. Kilic and L. Mostarda. Optimum Path Finding Framework for Drone Assisted Boat Rescue Missions. In AINA, Lecture Notes in Networks and Systems, 227:219–231. Springer, 2021.

[4] K. I. Kilic and L. Mostarda. Heuristic Drone Pathfinding Over Optimized Charging Station Grid. IEEE Access, 9:164070–164089, 2021.

[5] K. I. Kilic and L. Mostarda. Novel Concave Hull-Based Heuristic Algorithm For TSP. Operations Research Forum, Springer Nature, 3(2):25, 2022.