Global connectivity and collective coverage among Multiple Mobile Robots

SOMMAIRE

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Context & problematics

Context

- Ubiquitous and pervasive networks became a reality
- Ubiquitous and pervasive networks are composed of heterogeneous devices (sensors, robots, Smartphones, Laptops, …)
- New challenges/opportunities due to the heterogeneity of devices

Problematics

- How to make the devices able to communicate to each other
- How to allow the devices split the tasks/sub-tasks and agree on the assignement of the tasks in order to reach a common goal
- How to make the devices smart

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Ongoing works

Global connectivity and collective coverage among multiple mobile robots

Context

- To carry out cooperative tasks, robot team members need to communicate with each other

- Maintaining connectivity among multiple mobile robots is a crucial issue

State of art

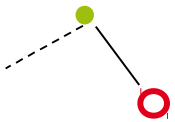
Approaches in literature can be classified into two groups :

- Local connectivity maintenance
- Global connectivity maintenance

Local connectivity maintenance

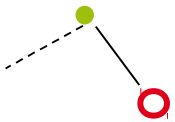
The initial set of edges which define the graph

connectivity must be always preserved over time.



Global connectivity maintenance

Allows suppression and creation of some edges as long as the overall connectivity of the graph is conserved.



Some strategies of connectivity maintenance

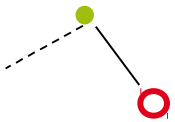
- Construction of an spanning tree
- Maximize the algebraic connectivity
- ...

Connected graph

- Multi-robot systems can be modeled as an undirected graph G= (V,E)

Definition 1 : A graph G is said to be connected if and only

if ∀ u,v ∈ V, there exists a path p(u,v)



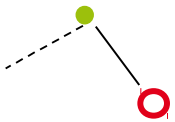
Spanning tree (ST)

Definition 2 : A spanning tree of an undirected graph G is the subgraph G* = (V,E*)

such as :

- There is no cycle in G*
- |E*| = n -1

Corollary 1 : The graph G is connected if and only if there exists a ST deduced from G.



Laplacian matrix and algebraic connectivity

- Given a undirected graph G, its Laplacian matrix L is defined as: **L(G) = D(G) – A(G)**

- The scalar λ is an eigenvalue of L if there exists a non-zero vector w such that : **L.w = λ.w**

The Laplacian matrix L(G) holds some interesting properties:

1- The eigenvalues of L(G) can be ordered such that:

$$0 = \lambda 1 \leq \lambda 2 \leq \lambda 3 \leq \ldots \leq \lambda n$$

2- **λ2 > 0 if and if only the graph G is connected**. λ2 is called also algebraic connectivity of the graph G

Trade-off between collective coverage and communication quality

- Maximizing the connectivity is important to ensure reliable communication

- Maximizing the collective coverage is needed

- Maximizing these two parameters simultaneously is difficult (if not impossible) : *maximize collective coverage may lead poor communication quality and conversely*

- **Need to capture the trade-off between collective coverage and communication quality**

Proposed approaches

- Centralized approach for global connectivity maintenance

- Distributed trained neural network controller

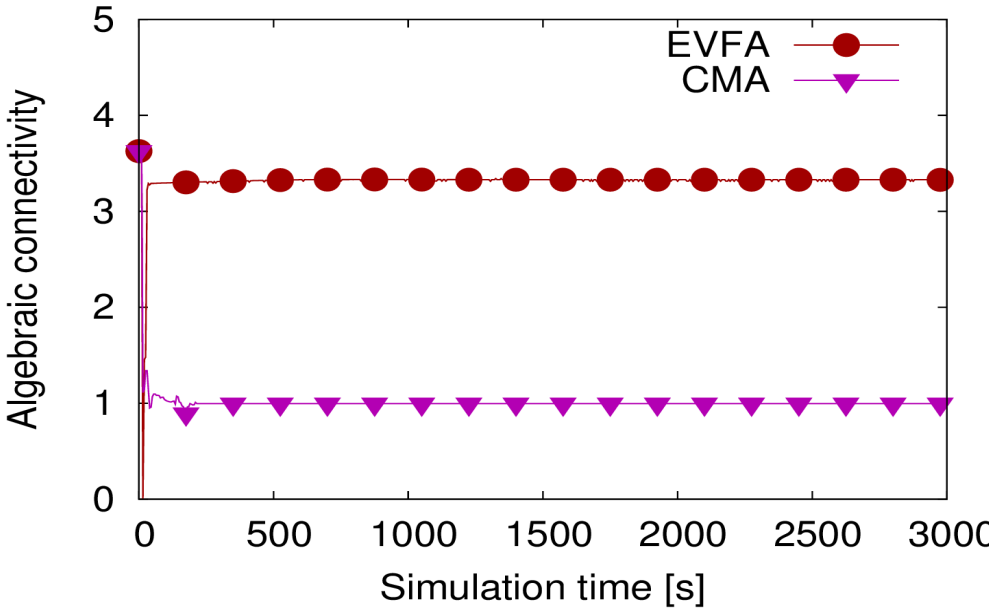
Centralized approach to maintain global connectivity between robots to a desired quality level

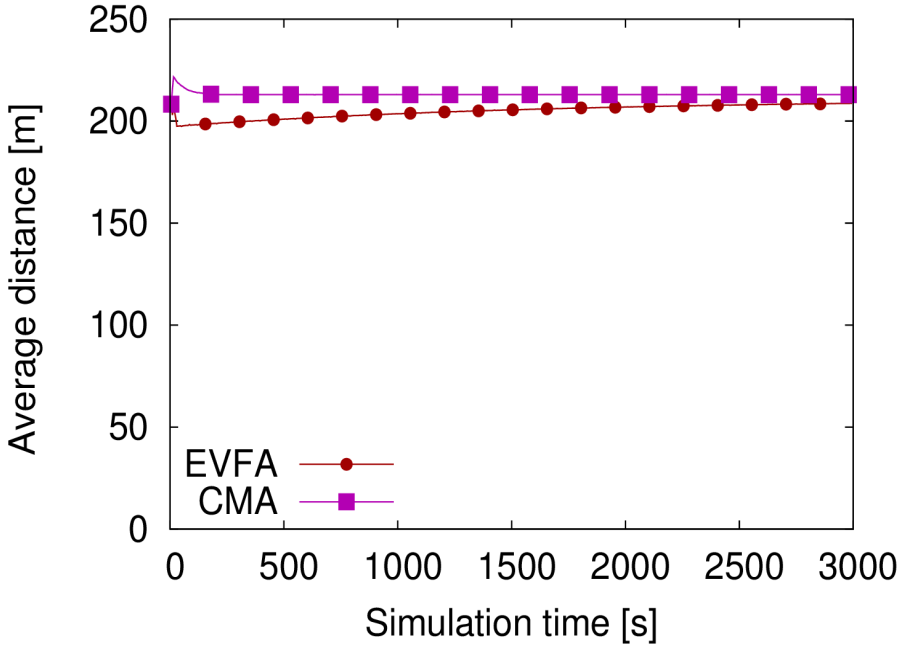
- Use of a modified version of virtual force algorithm (VFA) to control the robots' motion

- Compute algebraic connectivity metric to guarantee global connectivity maintenance (Centralized computation)

- Only move to the new position if λ2 is greater than zero

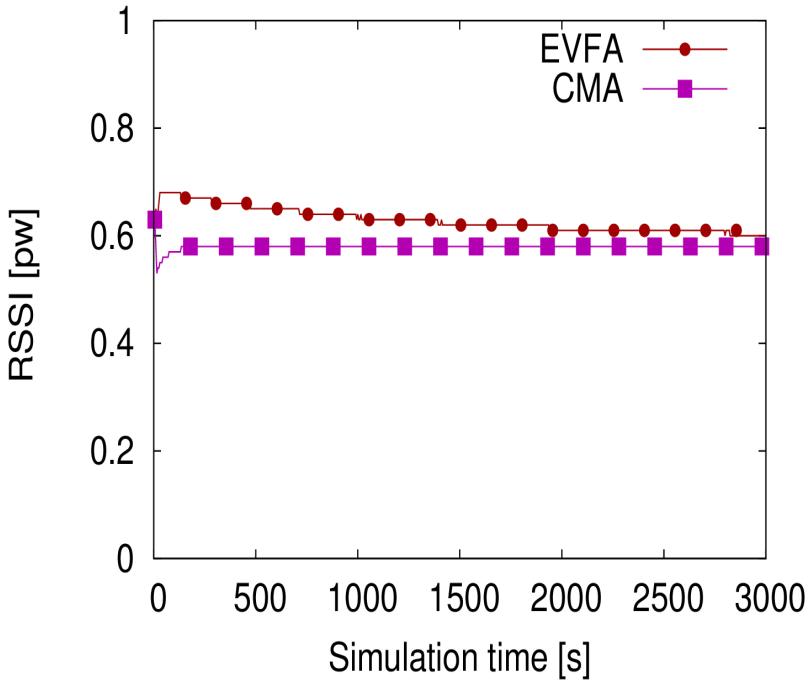
Obtained results with 5 robots

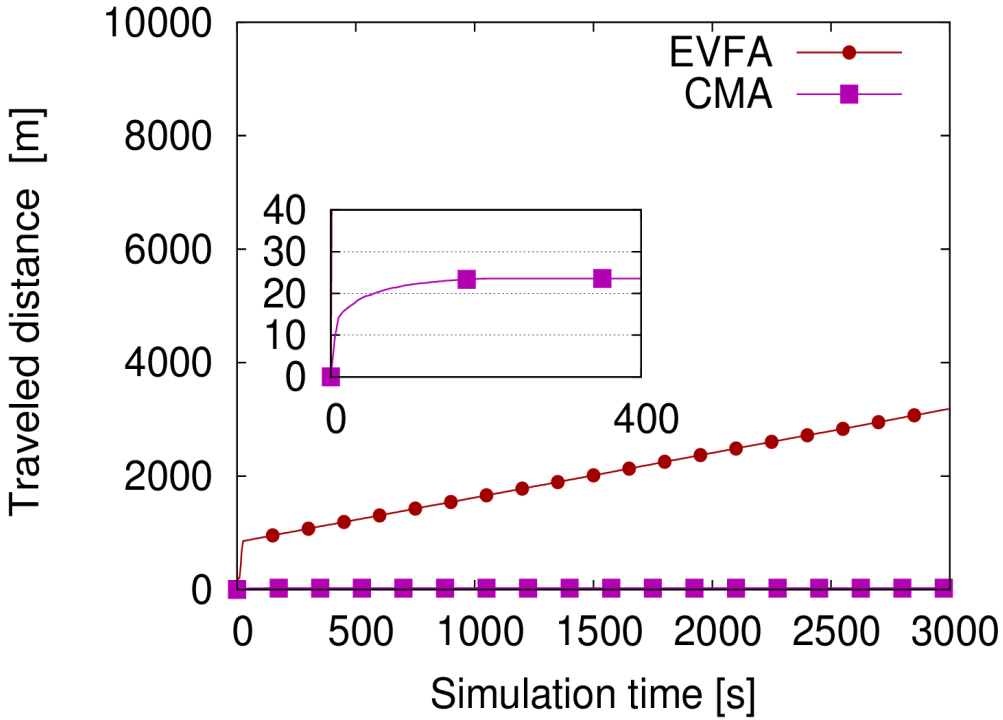




[EVFA] Jun Li & All, An extended virtual force-based approach to distributed self-deployment in mobile sensor networks

Obtained results with 5 robots





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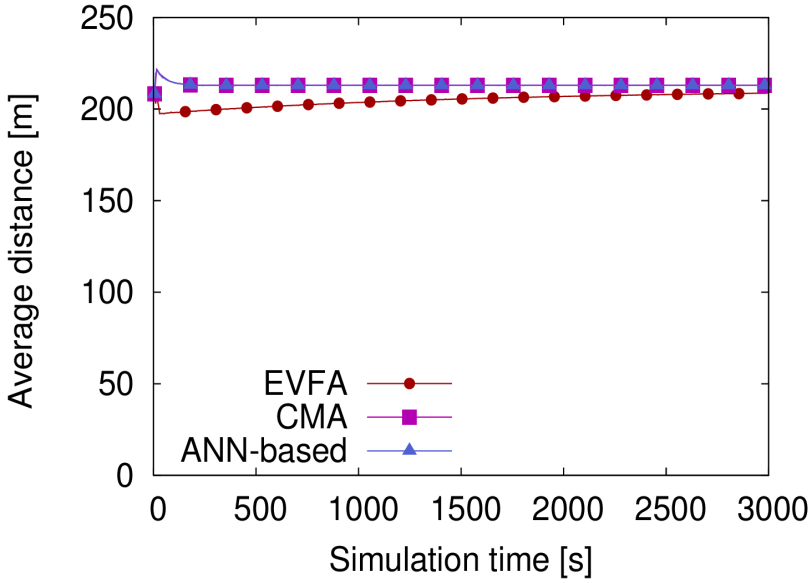
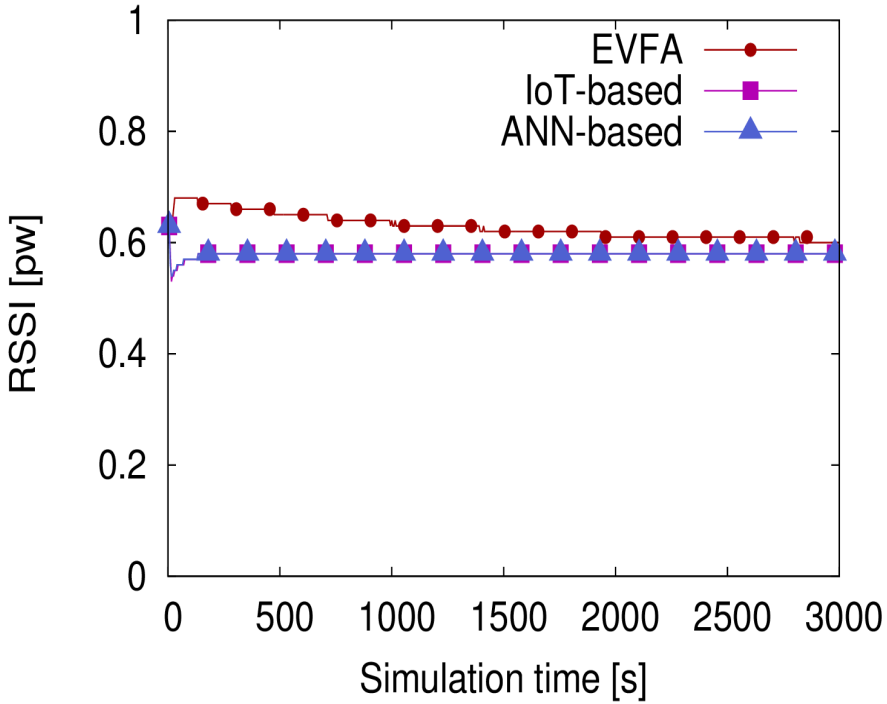
Maintain global connectivity between robots to a desired quality level using Neural Network

- Mimic the behaviors of the previous approach
- Data set was obtained by using our previous approach
- Inputs : distance and angle between two robots i,j
- Ouput : new position of robot i according its neighbor j
- Training algorithm : backpropagation

Obtained results with 5 robots





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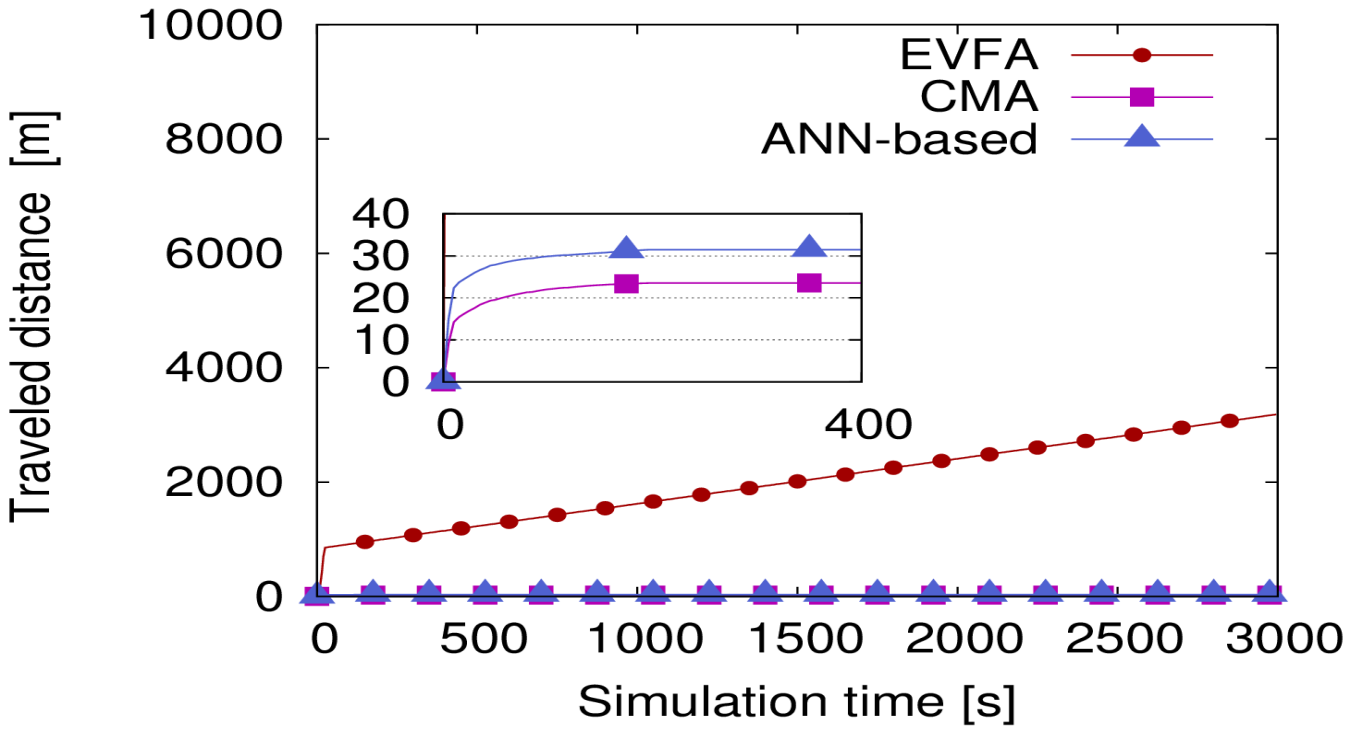

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Conclusion

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- Working on distributed communication and cooperation among heterogeneous devices

- Contribution on global connectivity maintenance and collective coverage among multiple mobile robots

- Two proposed approaches till now:
  - Centralized approach based on algebraic connectivity and VFA
  - Distributed approach based on neural network

Conclusion

- The proposed approaches tried to capture the trade-off between network coverage and communication quality

- The proposed algorithms allows the whole robot network converges to the desired distance/communication quality

- The proposed approaches outperform EVFA in terms of:
  - Traveled distance
  - Convergence time
- Our proposed methods always maintain the global connectivity

- Next step : add some heterogeneity in the system

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