Distributed Algorithms for Multi-Robot Observation of Multiple Moving Targets

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About this Paper

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Agenda

- Introduction
- Problem Description
- Approach
- Results
- Strengths and Weaknesses
- Related Works
- Summary

Introduction

- Motivation
  - Surveillance of moving targets
- Fixed sensors
  - Static/Known environments
  - Perfect sensors
- Sensor-based robots
  - Unknown/large environment
  - Limited sensor range

Problem Description

- Cooperative Multi-Robot Observation of Multiple Moving Targets (CMOMMT)
- Team of autonomous sensor-based robots
- Minimize total time targets escape observation by at least one team member
- CMOMMT Metric

CMOMMT Metric

- Definitions
  - S: two-dimensional bounded, enclosed space
  - V: team of m robots
  - O(t): set of n targets at time t
  - B(t): m x n matrix where

  - $B(t)=[b_{ij}(t)]_{m \times n}$ such that

    $b_{ij}(t)$ = 1 if robot v_i is observing a target

    0 otherwise

CMOMMT Metric

$$A = \sum_{t=1}^{T} \sum_{j=1}^{n} \frac{g(B(t), j)}{T}$$

Where:

g(B(t),j)= 1 if there exists an i such that $b_{ij}(t) = 1$

0 otherwise

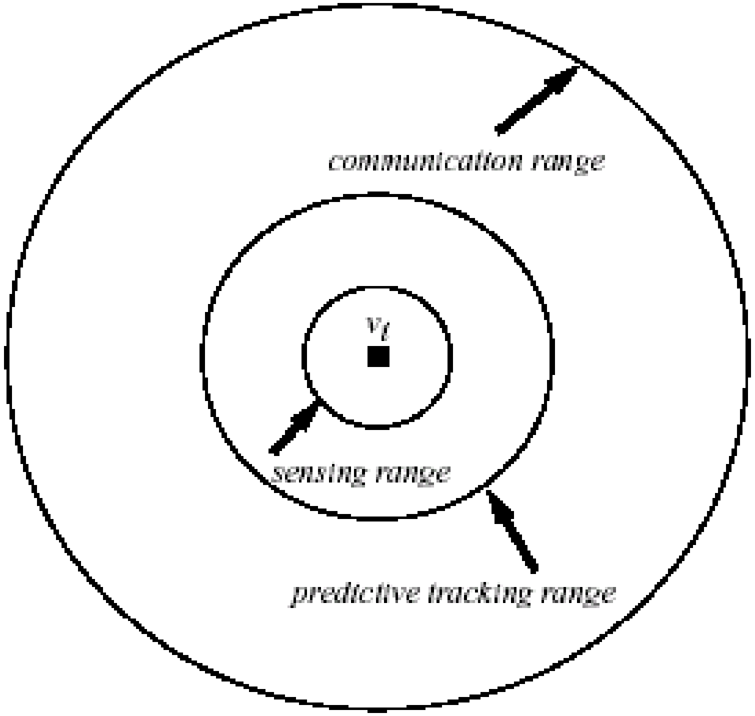
A = average number of targets under observation

Approach(1)

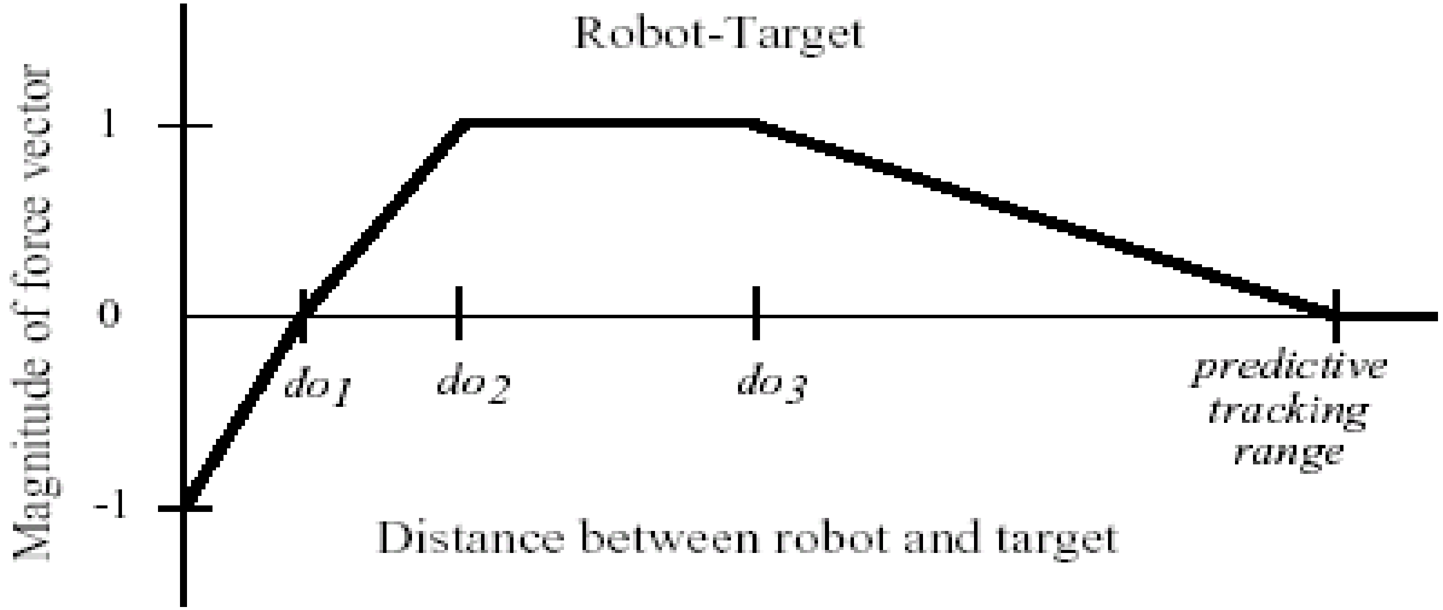
- Assumptions
  - No centralized control
  - Robots move dynamically
  - Limited range communications
  - Robots are faster than targets
  - Robots share known global coordinate system
  - Omni-directional sensors

Approach(2) A-CMOMMT

- A-CMOMMT
  - Weighted force vectors
  - Computed real time
  - Sensing range
  - Predictive tracking
  - Communications range

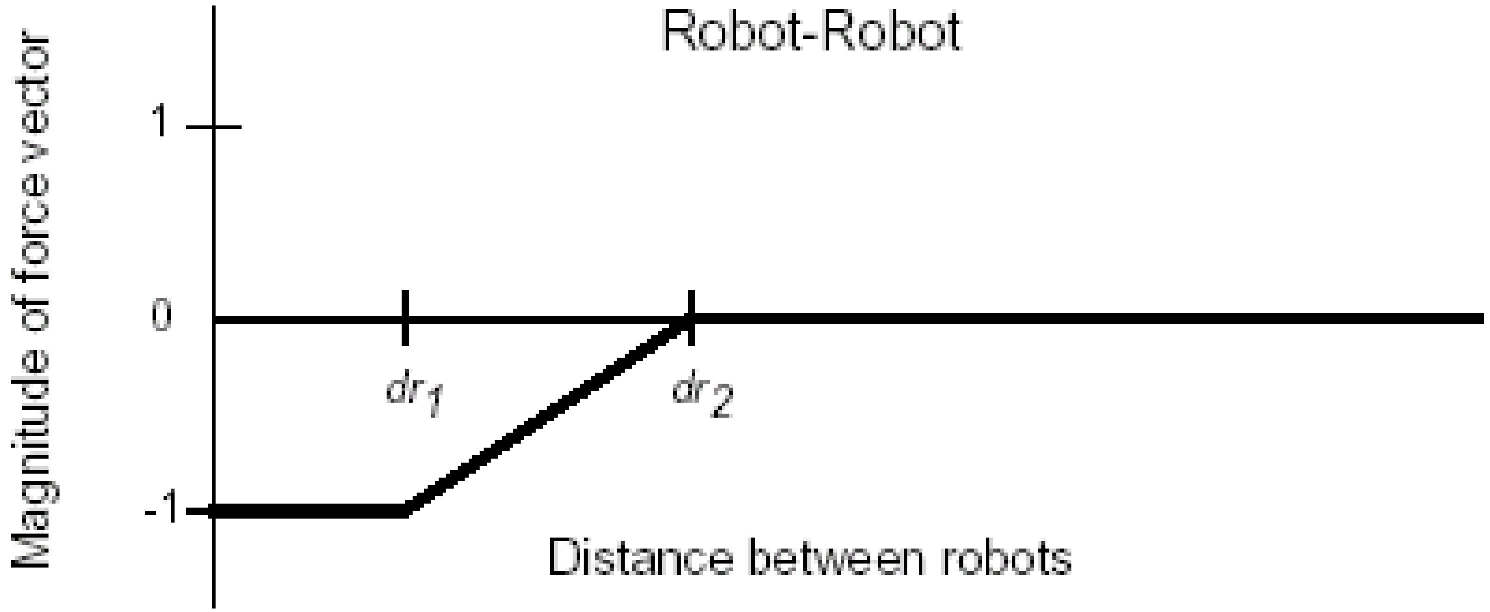


Local Force Vector Calculation(1)



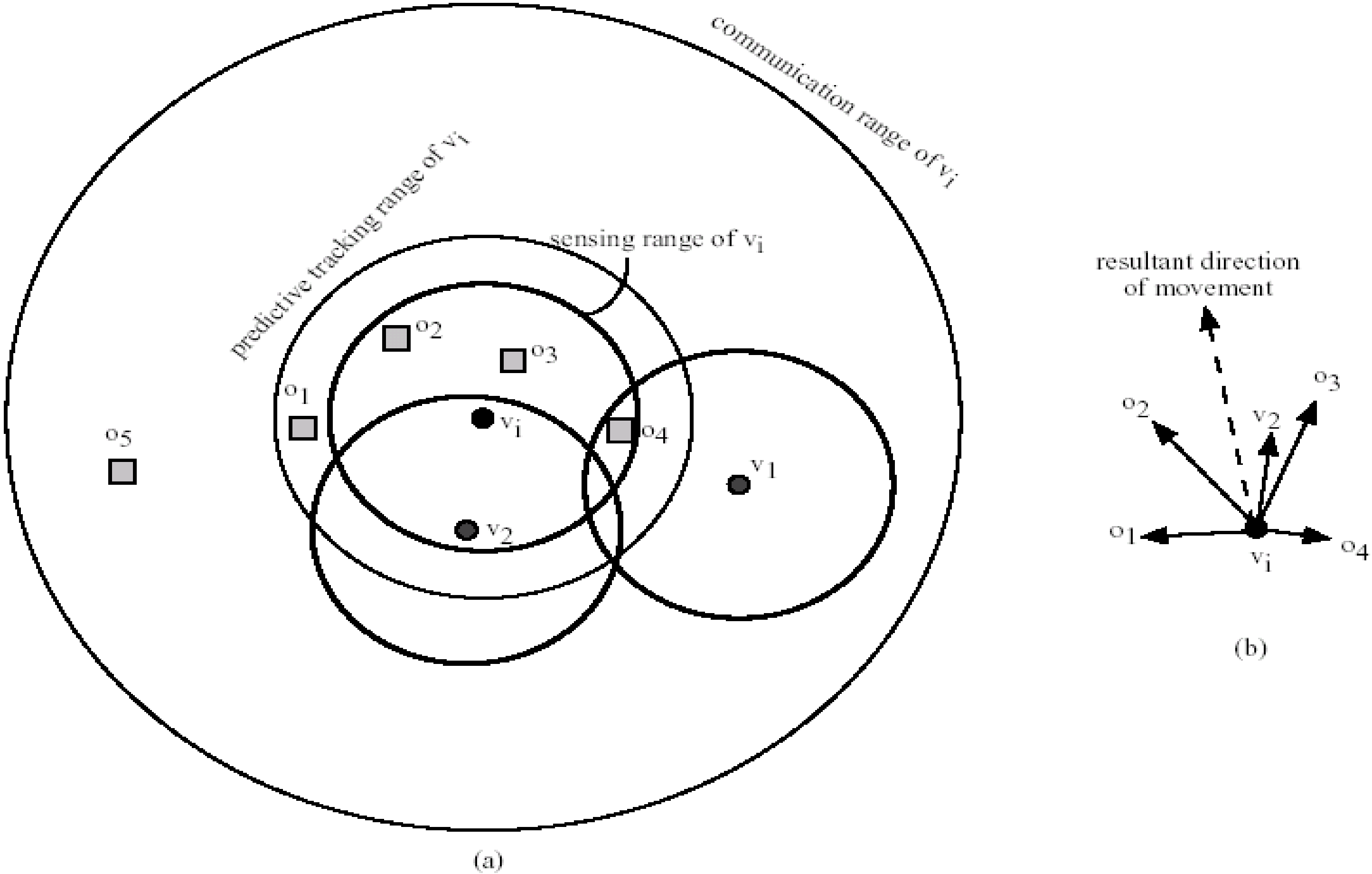
- Function defining the magnitude of the force vectors acting on a robot due to a nearby target

Local Force Vector Calculation(2)



- Function defining the magnitude of the force vector acting on a robot due to another robot

Combination of weighted local force vectors



Experimental Setup(1)

- Simulation and Mobile robots
- Four cooperative policies compared
  - A-CMOMMT (weighted local force vectors)
  - Local (non-weighted local force vectors)
  - Random (random/linear)
  - Fixed (robots remain where placed)
- Target movement
  - Random/Evasive (simulation test only)

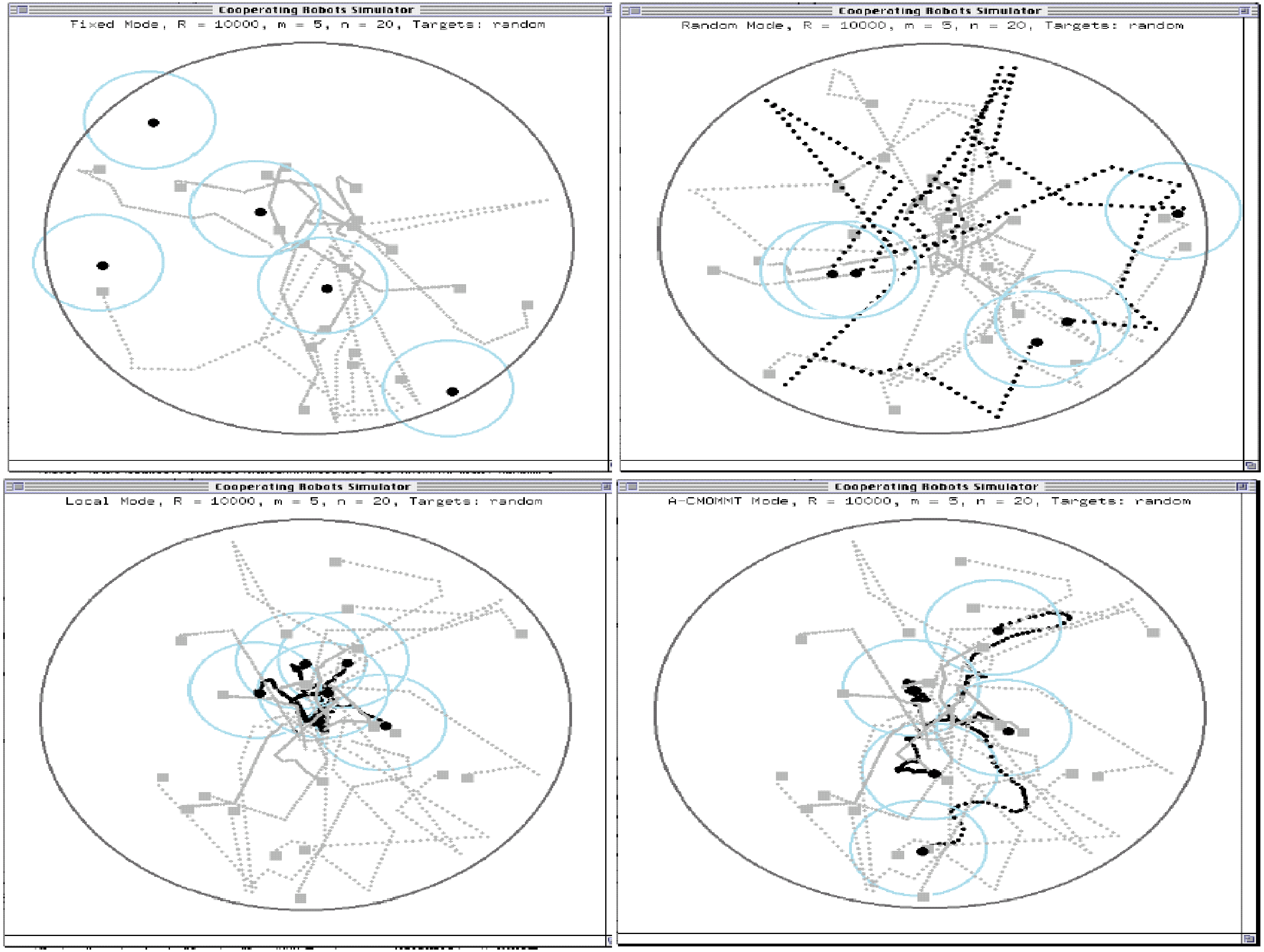
Experimental Setup(2)

- Force Vector Function Definitions
  - d_{o1} = 400
  - d_{o2} = 800
  - d_{o3} = 2600
  - Predictive tracking range = 3000
  - d_{r1} = 1250
  - d_{r2} = 2000

Evaluated A metric --Averaged 250 runs of 1-10 robots and 1-20 targets.

Radius R: $1000 < R < 50000$ units.

Experimental Results - Qualitative



Experimental Results Quantitative(1)

- Percentage improvement in simulation of A-CMOMMT and local over random, for R>10000, r=2600, and random target movement.

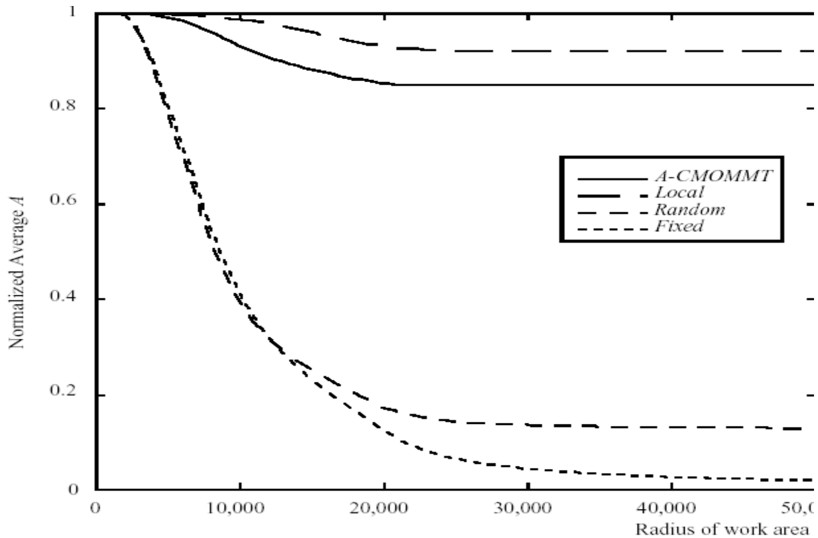
$\frac{n}{m}$	$\frac{1}{5}$	$\frac{1}{2}$	1	4	10
A-CMOMMT	654%	550%	600%	570%	511%
Local	708%	550%	525%	450%	389%

Experimental Results Quantitative(2)

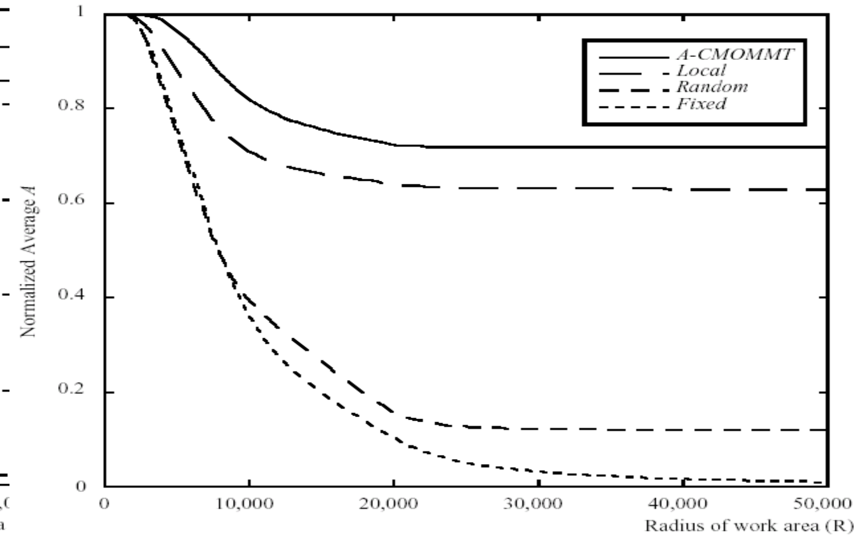
- Percentage improvement in simulation of A-COMMT over local, for R>10000, r = 2600, and random moving targets.

$\frac{n}{m}$	$\frac{1}{5}$	$\frac{1}{2}$	1	4	10
A-CMOMMT	-8%	0%	14%	27%	31%

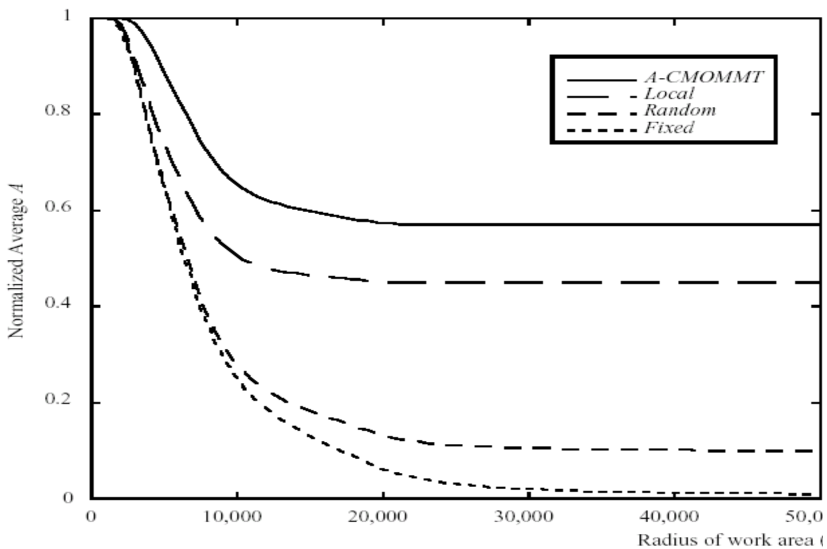
Experimental Results



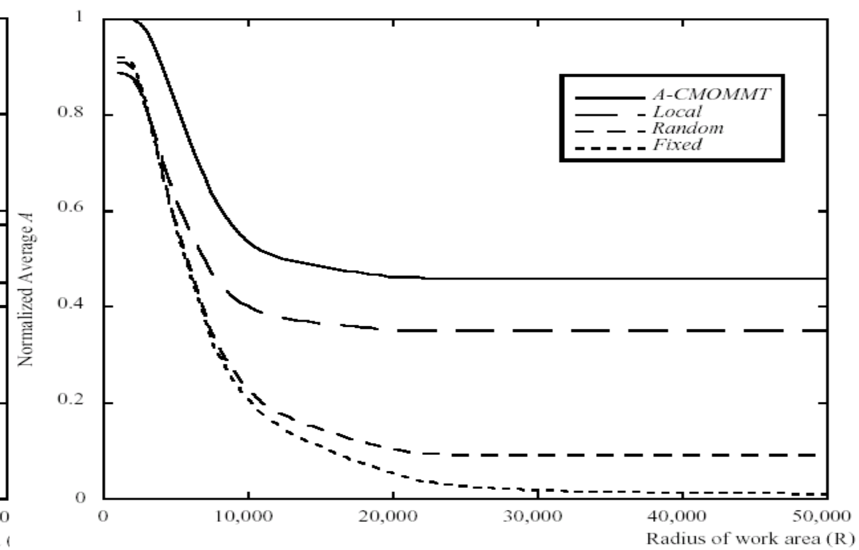
(a) n/m = 1/5, Targets move randomly



(c) n/m = 1, Targets move randomly



(d) n/m = 4, Targets move randomly



(e) n/m = 10, Targets move randomly

Strengths and Weaknesses

- Strengths
  - Useful in unknown environments
  - Can be implemented real-time
  - Scales to large numbers of targets and robots
- Weaknesses
  - Small number of targets may not be observed
  - Requires robots to communicate
  - Could incorporate a known path vector

Related Works

- ‘Art Gallery’-determine the number of fixed guards required to ensure coverage of an enclosed polygon.
- ‘Searchlight’-search for a mobile ‘robber’ with some number of fixed searchlights.
- ‘Visibility Based Motion Planning’-define a visibility region, trying to guarantee that a target will eventually be observed. Appears NP-hard.
- ‘Polygon Search’-presents necessary conditions to allow a search of a simple polygon by some number of searchers. Not implemented.

Summary-Contributions

- CMOMMT improves on non-weighted force vector solutions.
- Good for future studies in multi-robot learning in inherently cooperative tasks.
- Not computationally expensive.
- Results validated qualitatively as well as quantitatively.

Questions?

Thank you