Mutual Exclusion in Wireless Sensor and Actor Networks

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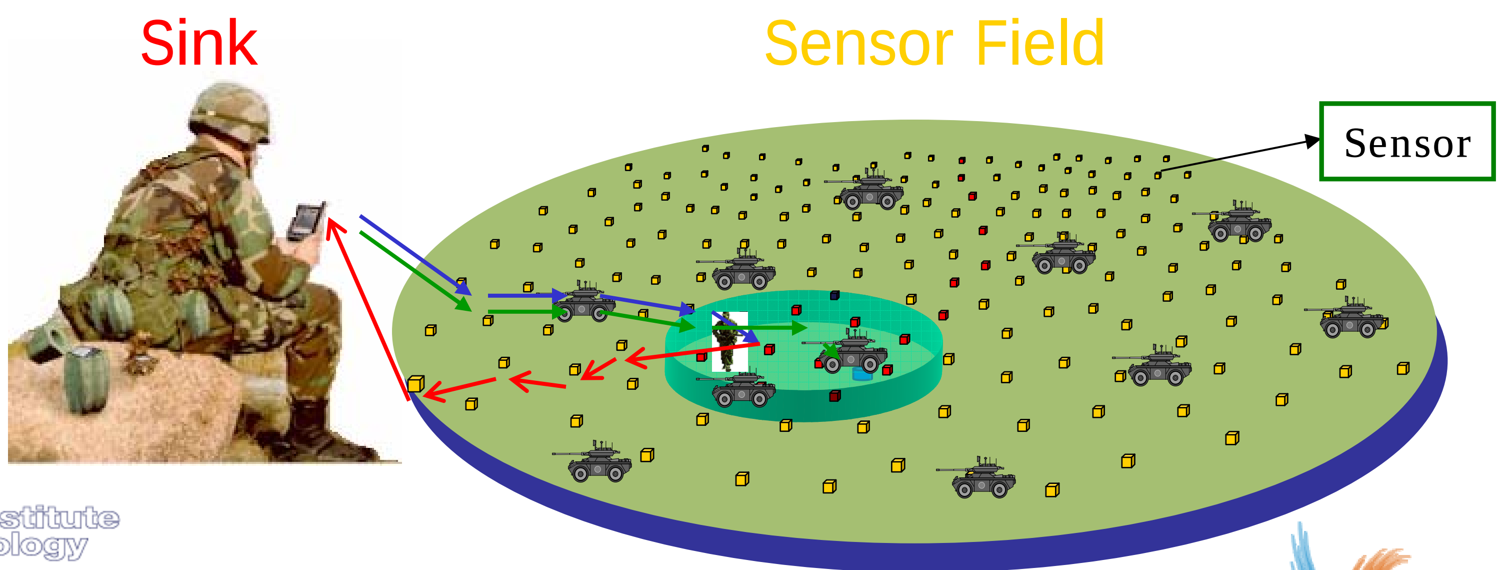
Wireless Sensor and Actor Networks

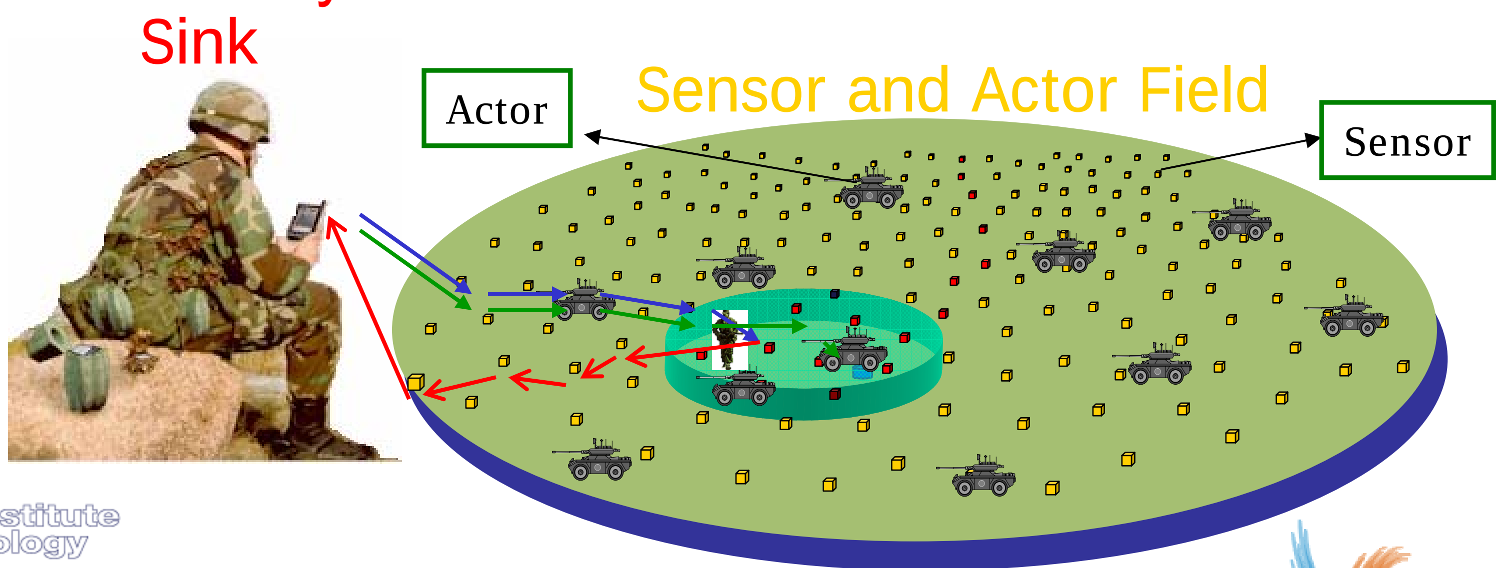
- Wireless Sensor Network (WSN): Multi-hop wireless network consisting of
  - Sink: central coordination entity that sends queries
  - Sensors: monitor phenomena and reports to sink
- Example for WSNs: Object tracking application
  - ☞ Performs only one type of action: sensing the environment



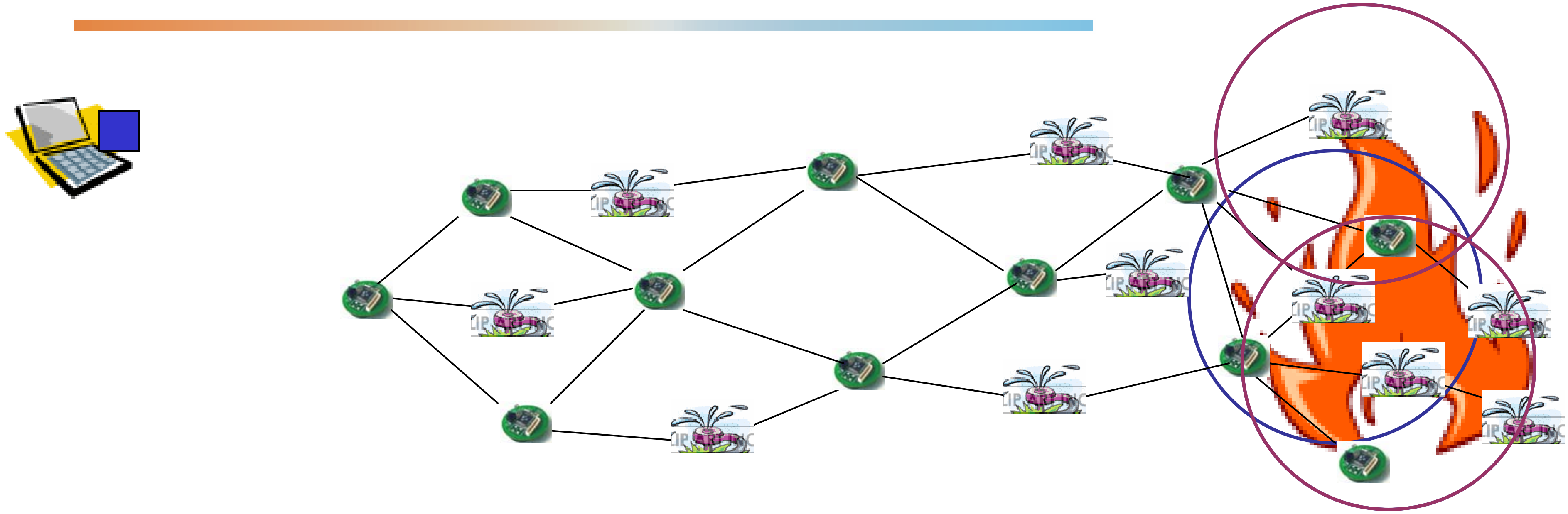
Wireless Sensor and Actor Networks

- What next?
  - If there are devices capable of acting on the environment, sink could issue a command
- Problems in Wireless Sensor and Actor Networks (WSANs) have not been extensively studied

☞ Identify the problem pertaining to acting on the environment only to the desired level



The Problem: Mutual Exclusion



- Three actors act
- While actually two actors are sufficient in this case

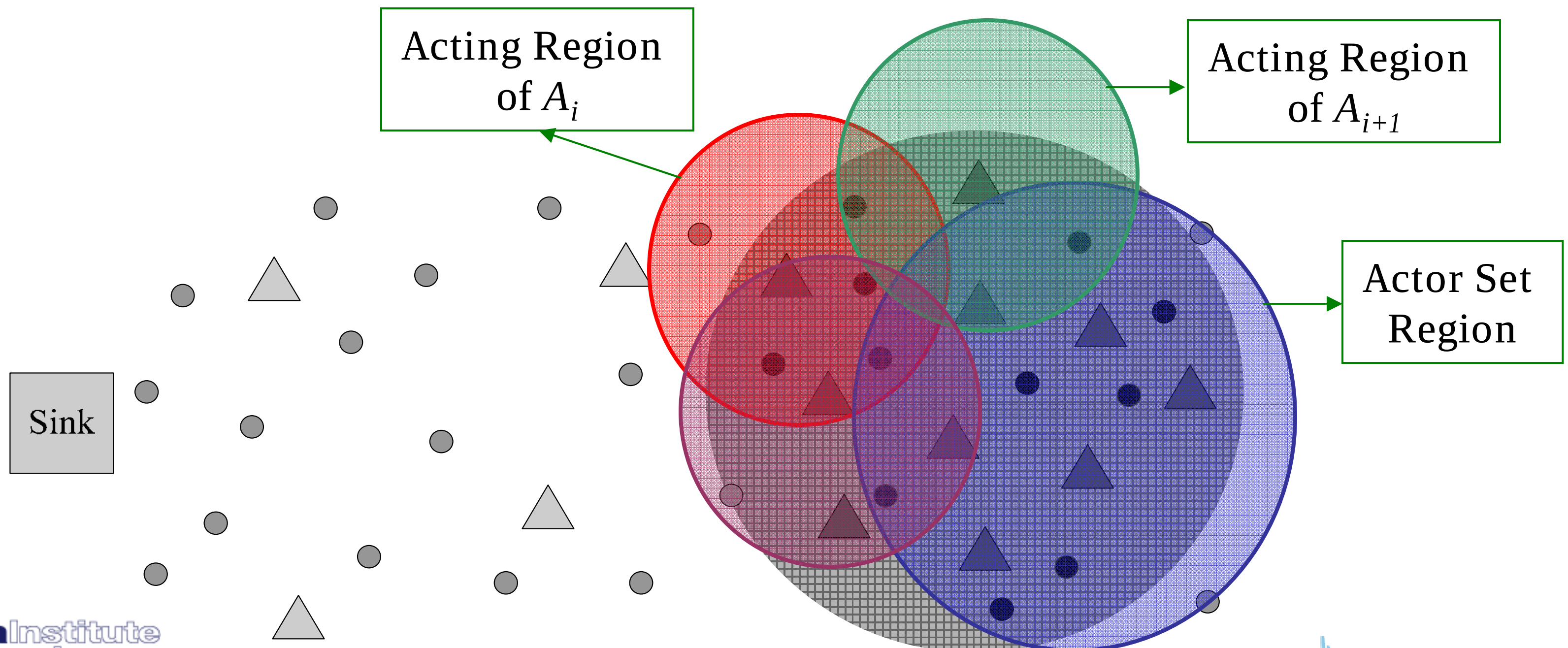
The Problem: Mutual Exclusion

- Mutual Exclusion: Identify a minimal set of actors to act for a directive
  - Requirement to act only to the desired level for a particular directive and location

- Outcome of lack of Mutual Exclusion
  - Inefficient usage of actor resources
  - Undesirable changes to the environment
    - Poison gas actors where one dose merely invalidates the subject but two doses can kill

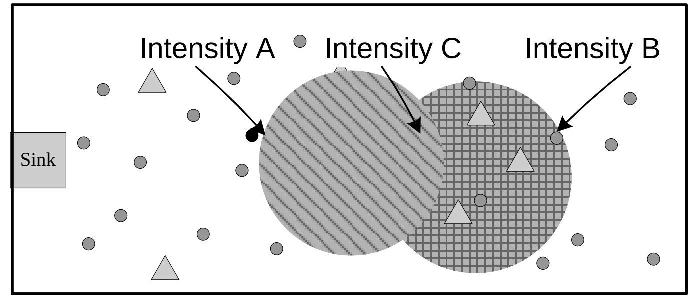
Types of Mutual Exclusion

- Resource Critical Mutual Exclusion
- Overlap-Type Critical Mutual Exclusion
- Overlap-Area Critical Mutual Exclusion
- Overlap-Intensity Critical Mutual Exclusion

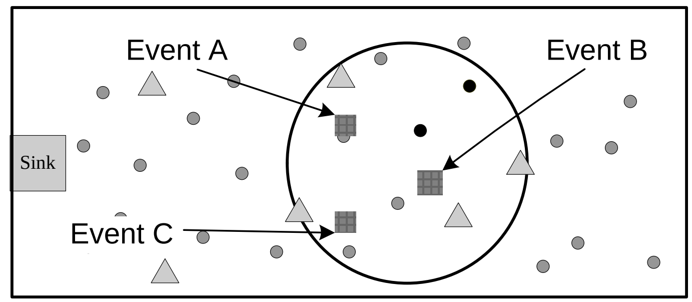


Challenges

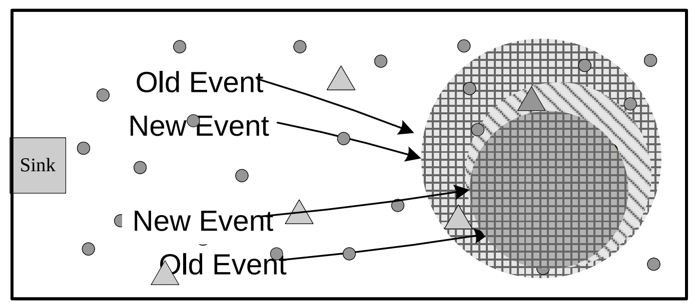
- Different Event Intensity
  - Event intensity may not be same across entire event region
  - Action performed should reflect desired intensity in each sub-region
- Point/Multi-point Events
  - Events can either be regional or (multi-)point
  - For (multi-)point events, minimize the number of actors that address all point events
- Event Dynamics
  - For multiple rounds of operation, event area may increase or decrease with time
  - Approach should adapt to determine the minimum set for the new event area
- Goals
  - 100% Correctness, Minimize Overhead



(a) Differing Event Intensity



(b) Point Events



(d) Event Decrease

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Centralized Set Cover (CSC)

- Value of an actor described by a benefit function
  - Benefit in terms of new area covered
  - Penalty in terms of existing overlaps and intensity of overlap
- Minimal set of actors that maximizes the overall benefit function
- Optimal solution: Minimum Set Cover (MSC) [GARUDA'04, SECON'06]
  - Minimize the number of blue nodes selected to cover all red nodes [SECON'06]
  - ☞ NP-hard [CARR'00, JOHNSON'74]
- Proposed solution: Greedy Centralized Set Cover (CSC) approach
  - Notion of dependency region similar to NC approach
  - Determine actor with maximum benefit function, MAX_ACTOR
  - Update the individual benefit function of all actors within the dependency region of the selected actor (MAX_ACTOR)
  - Competitive ratio of $O(R_{CX} \log(\Omega))$ [FEIGE'96, JOHNSON'74]

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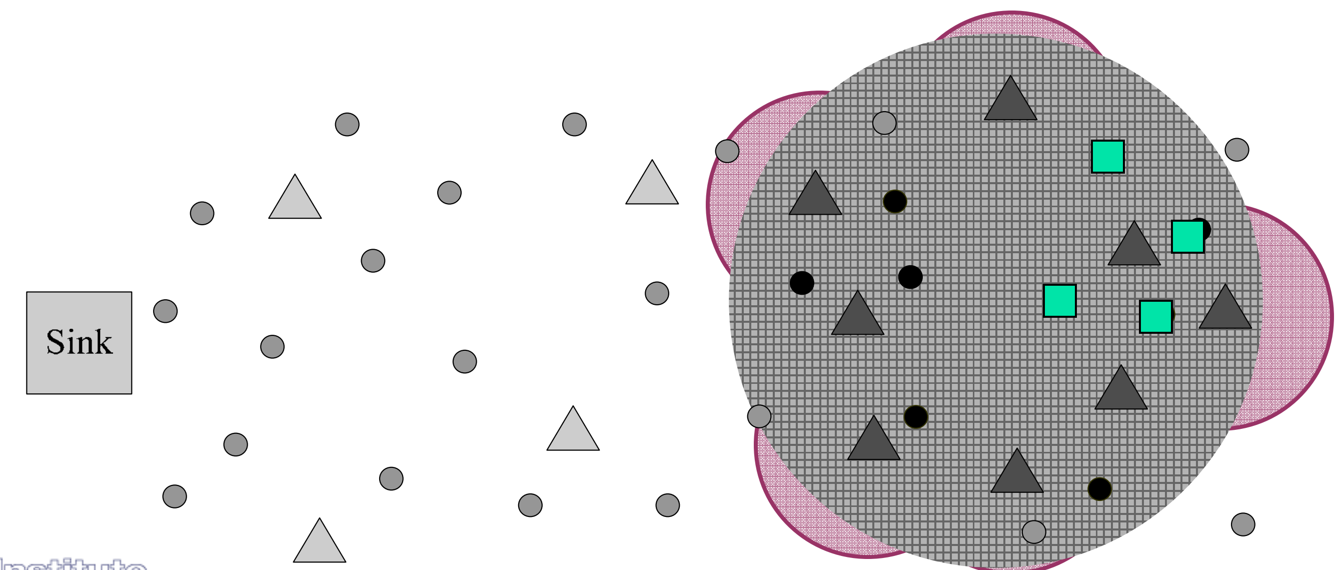
Distributed Approach Overview

- Distributed and fully localized approach that approximates the centralized approach
  - Assume that the sensing range = acting range = communication range
  - Assume each node knows its own location information [Bulusu'01]
  - Assume an underlying reliable delivery mechanism for directives [GARUDA'04]
  - Each node performs 2-hop neighbor discovery as part of initial setup [Meguerdichian'01]
- Notion of dependency region for both sensors and actors
- Determine initial benefit function of each actor within the event region
- ☞ Emulate the centralized approach by waiting for a time inversely proportional to the benefit function of the actor before execution
- Update benefit function of all actors within the dependency region of the actor that executed the directive
  - ☞ Neighborhood Backoff (NB)

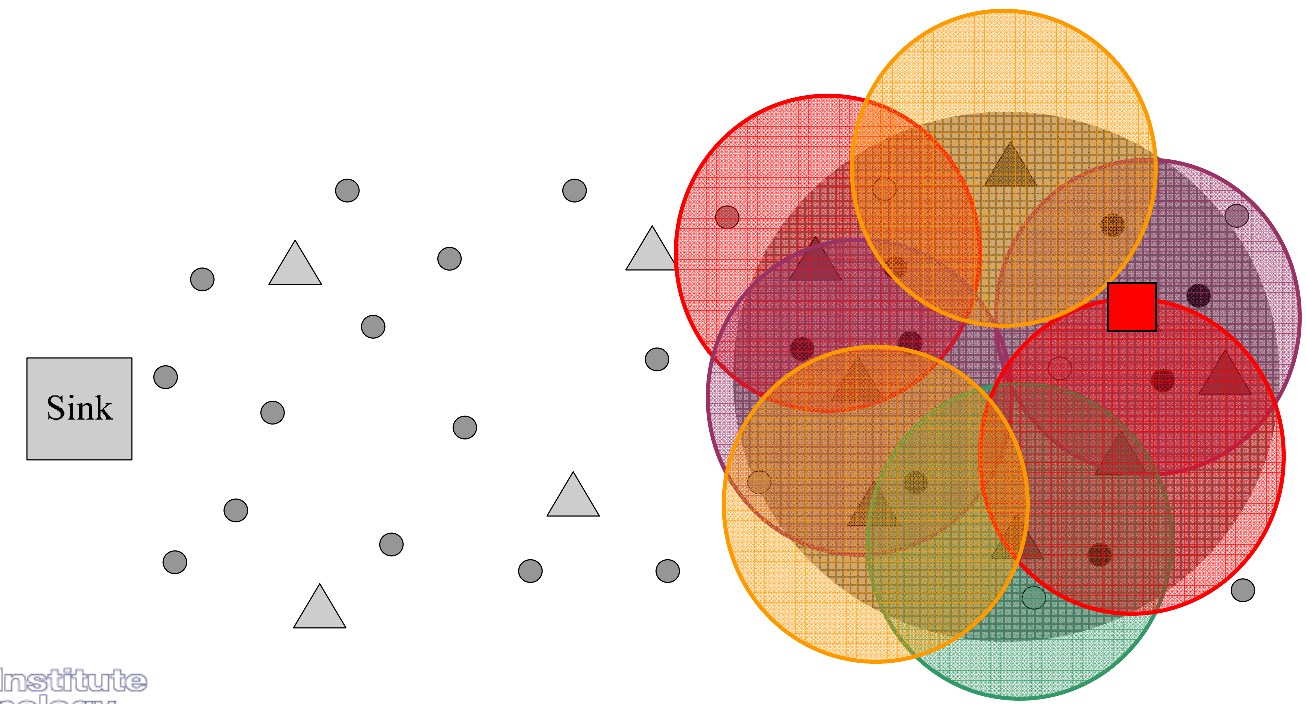
Distributed NB (1/2)

- Operations at Actors
  - Determine the estimate of event region based on *REQUEST()* messages from sensors
  - Determine initial benefit function, and the corresponding wait time
    - Wait time is inversely proportional to the benefit function



Distributed NB (2/2)

- Operations at Actors (Contd…)
  - Transmit NOTIFY() message when wait time reaches zero
  - At each iteration, more than one actor can be selected

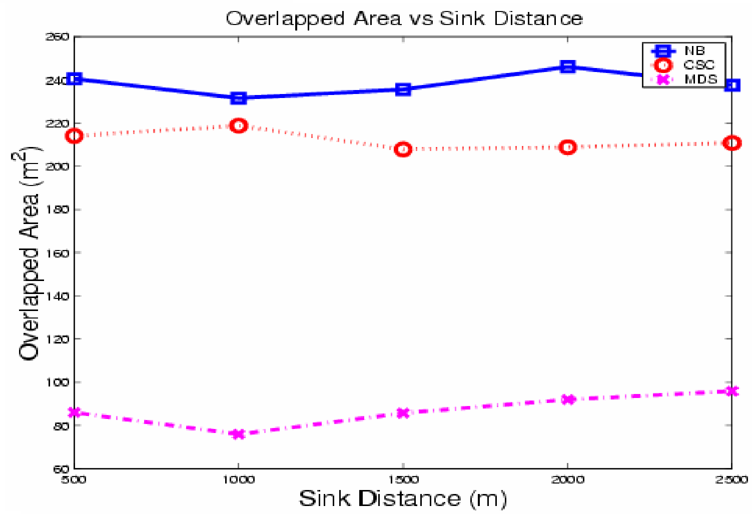


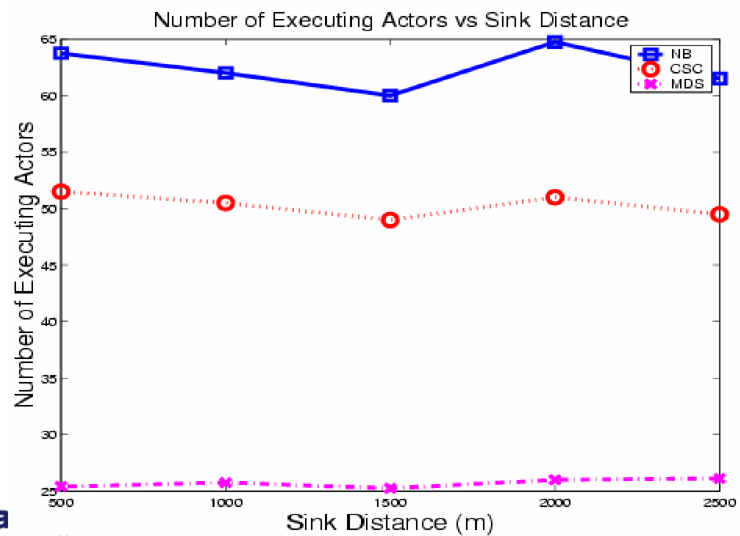
Performance: Simulation Environment

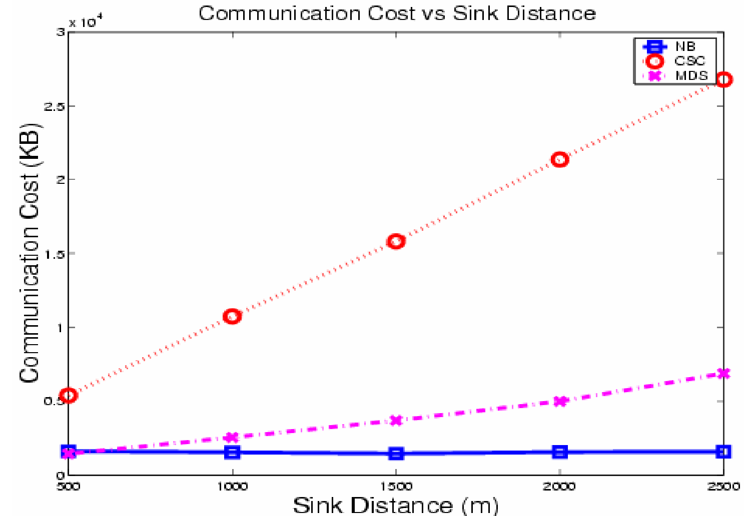
- Competing approaches
  - Centralized Set Cover (CSC)
  - Minimum Dominating Set (MDS) [GARUDA’04]
- Simulation environment:
  - Event-driven network simulator in C
  - 2000 sensors and 2000 actors in 3000m *3000m square area
  - Sensing, acting and communication range = 30m
  - Bounded delay = 10sec
- Metrics
  - Overlapped area (m^2)
  - Number of executing actors
  - Communication cost (KB)
  - Correctness (%of event area covered) – NB and CSC: 100% correctness

Performance: Event Distance to Sink

- ✓ MDS has only 70% correctness
- ✓ NB closely follows CSC in terms of overlapped area
- ✓ NB scales well with increasing sink-to-event distance







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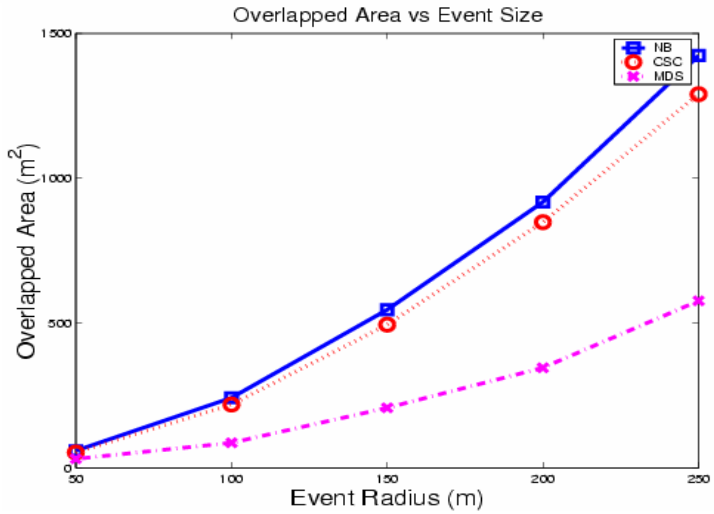
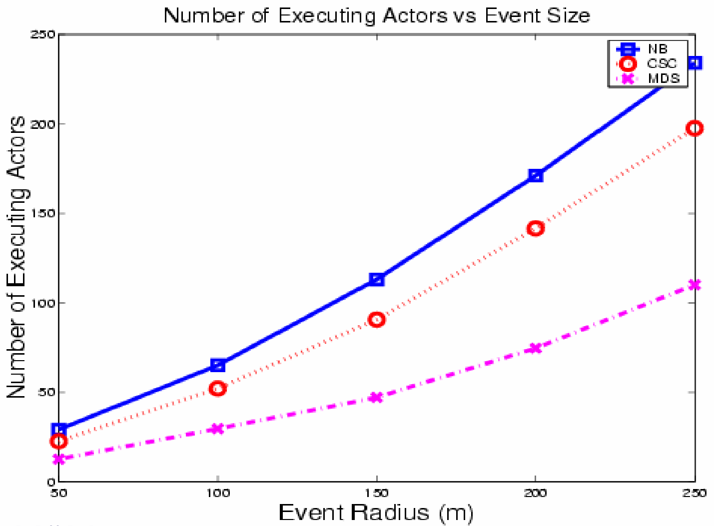
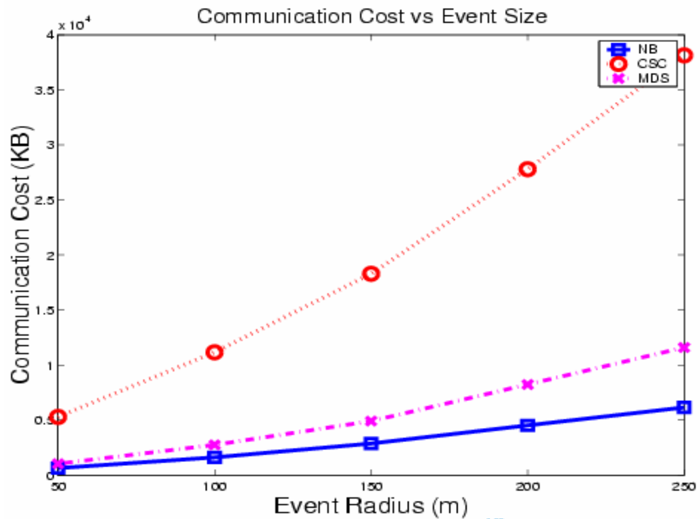
Performance: Event Area Size

- ✓ MDS has only 70% correctness
- ✓ NB closely approximates CSC with respect to overlapped area and number of executing actors
- ✓ NB has lower communication cost over MDS and CSC







Related Work

- Connected Sensor Cover [MOBIHOC'03]
  - Proposes a greedy centralized approach to determine the connected sensor cover that minimizes the overall energy consumption in a pure WSN
  - Need for a connected sensor cover
  - No delay bound
- Actor-Actor Coordination [MOBIHOC'05]
  - Determine the set of actors that maximizes the network lifetime when
    - The actors have different power levels and hence different transmission range
  - The remaining power left in the actor is also used as a constraint
  - Linear programming based approach
  - Does not capture the different types of mutual exclusion required
- Resource allocation problems
  - Conforms to classical definition of mutual exclusion and not the minimal set of actors

Conclusions

- Identified the problem of mutual exclusion in a wireless sensor and actor network
  - Identified the different types of mutual exclusion
  - Described the associated challenges
- Designed centralized and distributed approaches to address the different types of mutual exclusion and the challenges
- Evaluated the distributed approach with a baseline approach and the centralized approach