Mutual Exclusion in Wireless Sensor and Actor Networks

Introduction

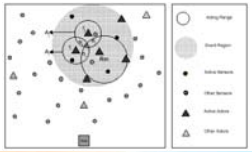
- Wireless Sensor Networks (WSN)
  - Consists of sink and sensors
  - Performs only one task: sensing the environment
- Wireless Sensor and Actor Networks (WSAN)
  - Consists of sink, sensors and actors
  - Performs both sensing (read) and operating (write) tasks on the environment
  - Allows automated sensing and execution for a given application
- Performing both read and write tasks leads to new challenges in WSANs
- One such challenge: Mutual Exclusion
  - Requirement to act only once for a given command and location
  - Example: Poisonous gas actors to invalidate subject
    - One dose invalidates subject, two doses kill the subject
    - Need to administer correct dosage

The Problem: Mutual Exclusion

- Conventional Mutual Exclusion: Provides access to critical shared resource
  - Safety: Only one process is using the critical resource
  - Liveness: Each process waits finite amount of time to access the critical resource
- Mutual Exclusion in WSANs: Execute a given command exactly once (or desired number of times) for any particular location irrespective of the distribution of actors
  - Safety: Only the desired number of actors act
  - One-time occurrence: Once an actor acts on a location, ensure no other actor acts for that command
- Relaxed Definition: Choose a minimal set of actors such that the overlap between acting regions is minimal.

Illustration of Mutual Exclusion

- Definitions for illustration
  - Rm: Region covered by set of actors already included as part of actor cover
  - r_i and r_j: New area covered by actor i and j respectively
  - n_i and n_j: New overlap area for actor i and j respectively
  - o_i and o_j : Old overlap area for actor i and j respectively
- One type of mutual exclusion is to choose i and j such that, (r_i U r_j U Rm) is maximized, and (n_i U n_j U o_i U o_j) is minimized



Types of Mutual Exclusion

- Conservation of actor resources
  - Maximize the non-overlapped region within the event region
  - Does not matter what happens with the overlapping region or how many times the overlap occurs in those regions
  - Example: Fire extinguisher system with sprinkler actors, where the amount of water is limited
- Binary decision making
  - Reduce the new overlap region, while also maximizing the non-overlapped region
  - Example: Automated trucks for leveling a region, where once part of a region has exceeded the limit, it can be overloaded
- Fine-grained decision making
  - Reduce both new and old overlap regions, while maximizing the non-overlapped region
  - Example: Fire extinguisher system with sprinkler actors, where once the region has exceeded the desired dosage, flooding occurs

Greedy Centralized Approach

- Definitions
  - Minimal Actor Cover: Minimum set of actors that covers the event region and satisfies the mutual exclusion definition
  - Candidate Actor: Actor that has overlapping region with event region and is not fully enclosed by the actor cover at that stage
- Greedy approach
  - Greedy, centralized solution to compute minimal actor cover
  - Select the maximum benefit function actor at each stage
  - Add the actor to actor cover and update the region to be covered

Compute the minimal actor cover for region R_C

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M: The set of actors selected as part of actor cover
    at any given stage
R_M: Region covered by M
ω = Ω
while (R_C ⊄ R_M)
    MAX_BENEFIT = 0 (or) -α · π · R_i^2
        (or) -β · π · R_i^2
    for each a_i ∈ ω
        VM_i = Benefit function of a_i
        if (VM_i > MAX_BENEFIT)
            MAX_BENEFIT = r_i
            MAX_ACTOR = i
        end if;
    end for;
    M = M ⋃ MAX_ACTOR
    R_M = R_M + MAX_BENEFIT
    ω = ω - MAX_ACTOR
    for each (a_i ∈ ω) and ((R_i ⋂ R_MAX_ACTOR) ≠ 0)
        Update r_i, o_i, n_i
    end for;
end while;
return M
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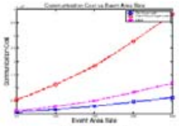
Design of Distributed Approach

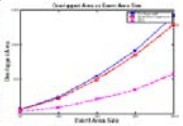
- Dependency region: maximum region within which a sensor or actor can have impact on another actor
  - For sensor, dependency region = area covered by (sensing range + acting range)
  - For actor, dependency region = area covered by (2 x acting range)
- Distributed approach: pseudo-randomized approach that approximates the greedy approach by adjusting the waiting time for acting based on the benefit function of actors
  - Determination of initial benefit function of actors based on the requests received from sensors to actors within the dependency region
  - Adjusting the waiting time to be inversely proportional to the initial benefit function of the actor. If benefit function is low, waiting time is large and vice versa
  - Updating the benefit function of all actors within its dependency region once an actor has acted on a command

Performance Evaluation (1/2)

- Total traffic and overlapped area for greedy centralized approach (MSC), proposed approach and Minimum Dominating Set (MDS) with varying event area size
  - Proposed approach has minimal traffic overhead
  - Proposed approach has similar overlap area to the centralized
  - MDS does not cover the entire event region but proposed approach and MSC covers the entire region



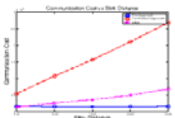
(a) Total Traffic



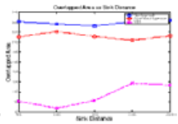
(b) Overlapped Area

Performance Evaluation (2/2)

- Total traffic and overlapped area for greedy centralized approach (MSC), proposed approach and Minimum Dominating Set (MDS) with varying event distance to sink
  - Proposed approach has minimal traffic overhead and it is constant with distance from event to sink
  - Proposed approach has similar overlap area to the centralized
  - MDS does not cover the entire event region as before



(c) Total Traffic



(d) Overlapped Area

Conclusions and Future Work

- Conclusions
  - Identified the different types of mutual exclusion in WSANs with example
  - Designed the centralized, greedy approach to address the problem in terms of benefit function
  - Proposed a distributed realization of the greedy approach
- Future Work
  - To prove the optimality of the greedy, centralized approach for all flavors
  - To understand the differences in the optimality of the centralized and distributed approach in terms of the final minimal actor cover and optimality
  - To understand the relationship between the traffic overhead, overlapping region and increasing node density for these approaches
- http://www.ece.gatech.edu/research/GNAN

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