Probabilistic Coverage for Object Tracking in Sensor Networks

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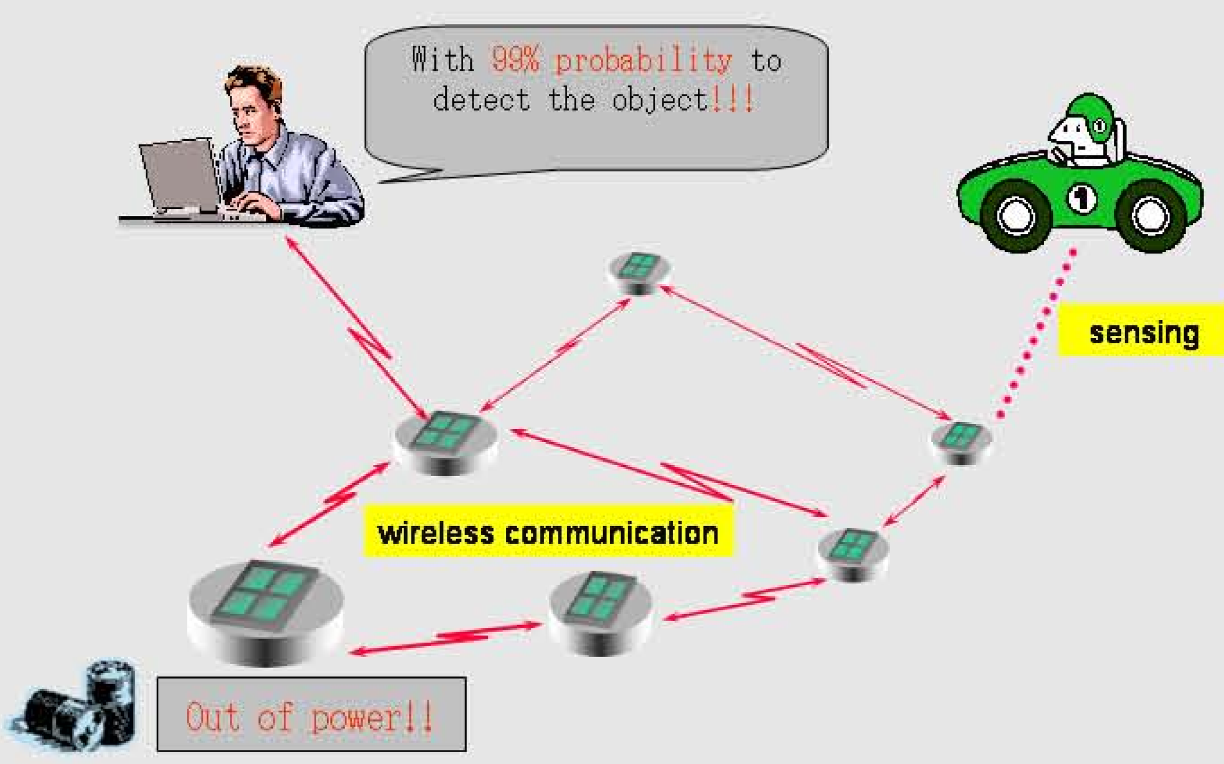
Motivation

- The object-tracking quality and system lifetime are two conflicting aspects of a sensor network.
- Full coverage is too expensive to support long-time monitoring applications.
- Probabilistic coverage is a more appropriate approach, in which any point in a sensing field is sensed with a certain probability at any time.

Problem Statement

Given an object-tracking quality requirement, such as the detection probability, how can we schedule sensors at the same time to extend the system lifetime?



Objective

To quantify the object-tracking quality under given sensing schedules and to guide new protocol design.

Model Assumption

- Nodes are randomly and independently deployed on a square field;
- An object travels across the field with a constant speed along a straight line.

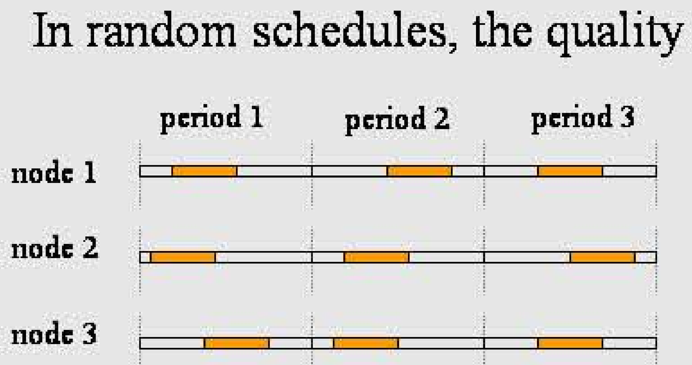
notation	meaning
d	density of sensors
R	sensing radius of a sensor
v	constant velocity of a motion object
P	sensing period of sensors
f	active ratio of sensors in P
t_a	observation interval

Object-Tracking Quality Metrics

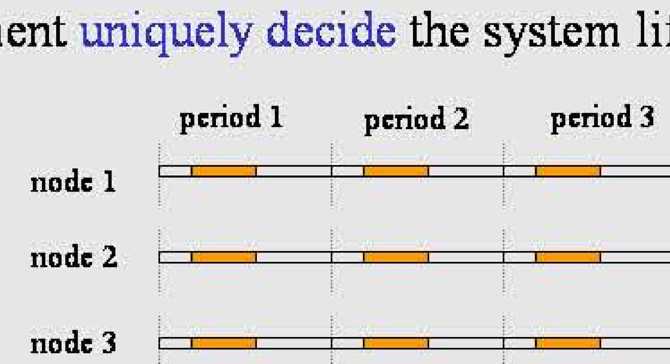
- Detection Probability (*DP*): the expected probability the object being detected in a given observation interval.
- Stealth Distance (*SD*): the average distance the object travelled before it is detected for the first time.
- System Lifetime: the working duration of the system when satisfying the required object-tracking quality.

Random Sensing Schedule and Synchronized Sensing Schedule

In random schedules, the quality requirement uniquely decide the system lifetime.



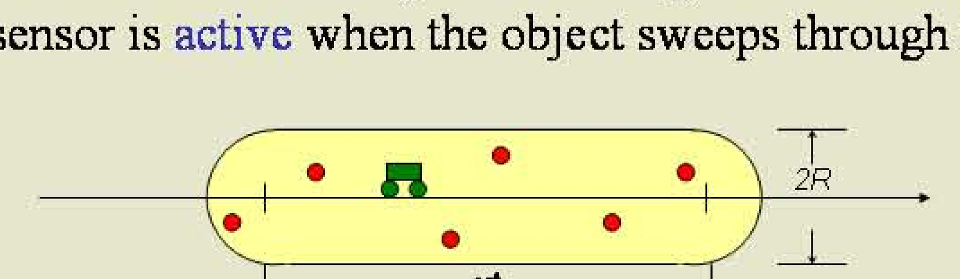
Random Sensing Schedule



Synchronized Sensing Schedule

Random Schedule Analysis

- For a specific sensor to detect the motion object, two conditions must be satisfied:
  - The sensor must be in a specific oblong area called active area;
  - The sensor is active when the object sweeps through its sensing range.



- The detection probability of one single sensor is the integral of the detection probability at a specific point over the whole active area.
- The DP is an exponential function of the detection probability of a single node: $DP = 1 - e^{-\lambda \tilde{P}r}$, where $\tilde{P}r = f + \frac{\pi R^2 t_a}{(vt_a \cdot 2R + \pi R^2)P}$ for fast objects.
- The SD is the integral of the DP over the positive time domain.

Comparison of Two Random Schedules

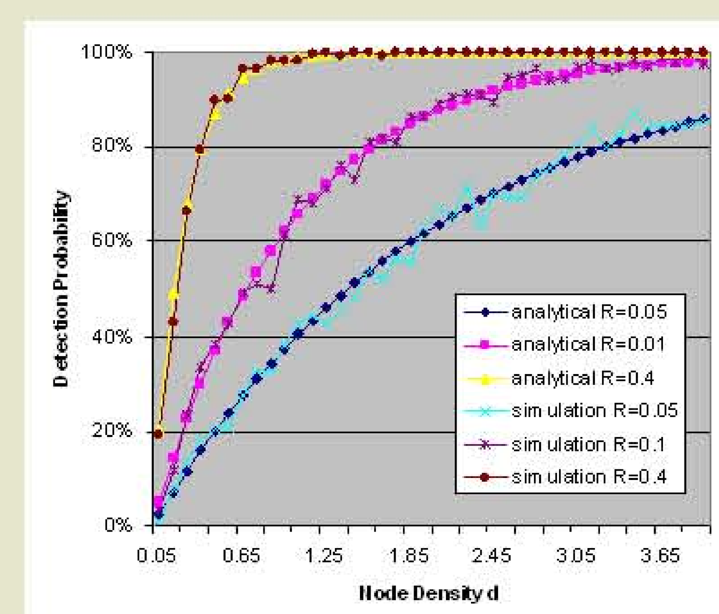
- In uniform schedule, all nodes sense with the same sensing period *P*.
- In set-based schedule, nodes are equally divided into ***k*** sets and are scheduled with period ***P/k*** in a rotating fashion.

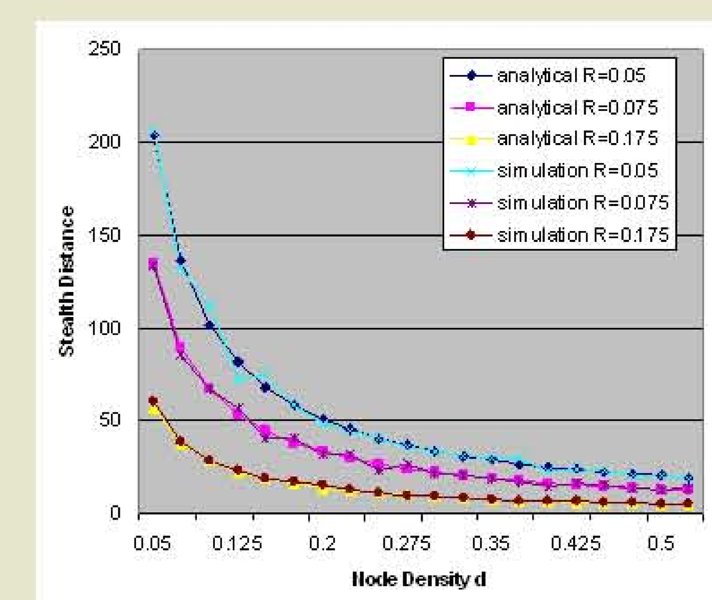
We proved that these two schedules have the same DP and SD for fast objects.

Synchronized Schedule Analysis

In this case, DP is an exponential function of the node density and the expected detection probability of one single sensor.

Analytical Results of Random Schedules





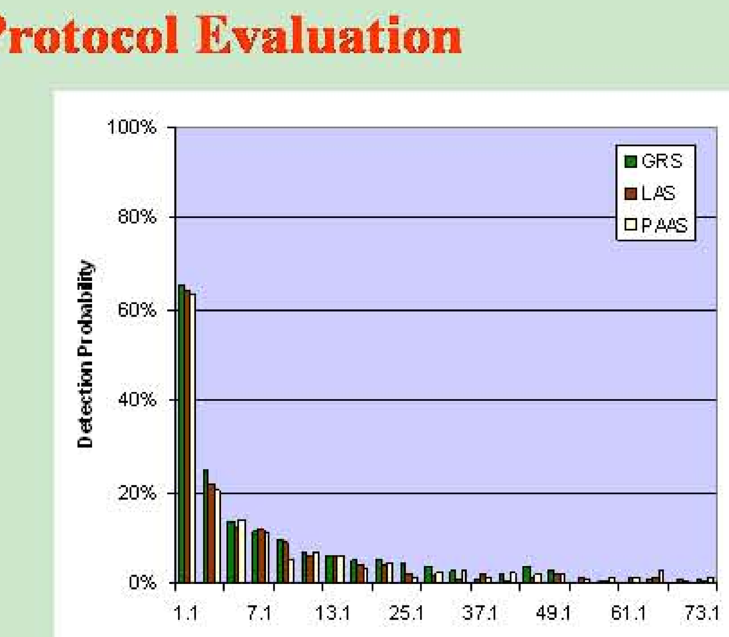
- The simulation results match the analytical curves well, which validates the correctness of our derivations.
- Random schedule outperforms synchronized schedule, but the latter has better performance of worst cases.
- SD increases linearly as the increase of P when fixing ***d***.

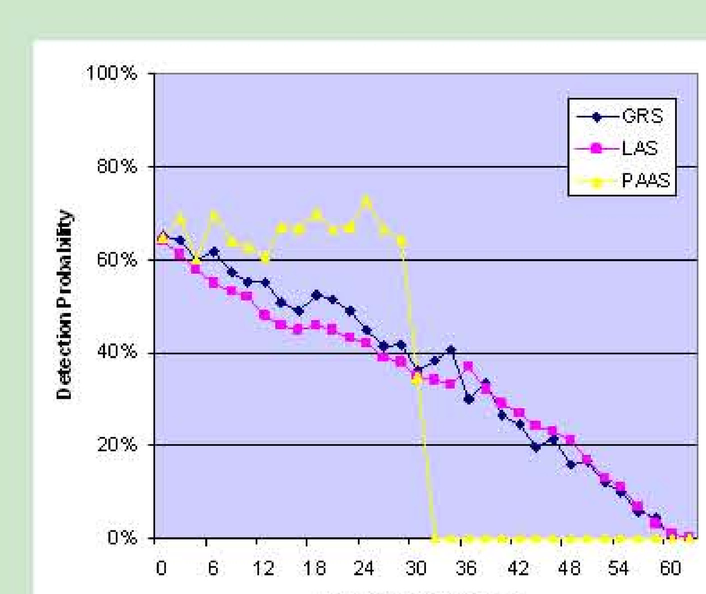
	DP	*SD*
d↑	↑	↓
R↑	↑	↓
v↑	↑	↑
ta↑	↑	
f↑	↑	↓
P↑	↓	↑

Design of Power Efficient Algorithms

- Global Random Schedule (GRS). Nodes sense the field with the maximum possible periods satisfying the object-tracking quality requirements.
- Localized Asynchronous Schedule (LAS). Nodes uses its local density to infer the maximum sensing periods to meet the object-tracking quality requirement.
- Power-Aware Asynchronous Schedule (PAAS). Nodes can sense with periods according to their remaining power and deplete their power simultaneously.

Protocol Evaluation





- GRS, LAS, and PAAS can achieve the same *DP* at the beginning.
- PAAS have a longer working time than GRS and LAS.
- After the system lifetime, the *DP* in PAAS directly drops to 0. By contrast, GRS and LAS can still provide an exponentially-degraded *DP*.

Contributions of Our Work

- Our work is one of the earliest to quantify the object-tracking quality of random schedule and synchronized schedule under given assumptions.
- Our model can give solid and thorough understanding about various protocols.
- Many protocols can be incorporated into our model by approximating parameters.
- Our model can direct new protocol design.