Energy-Efficient Continuous and Event-Driven Monitoring

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Maximum Sensor Network Lifetime Problem

A formal definition of the energy preserving scheduling problem

- **Sensor cover**: A set of sensors $C$ covering $R$.
- **A monitoring schedule**: a set of pairs $(C_i, t_i), \ldots, (C_k, t_k)$.
  - $C_i$ is a sensor cover;
  - $t_i$ is time during which $C_i$ is active.

Maximum Sensor Network Lifetime problem

- **Given**: a monitored region $R$, a set of sensors $p_1, \ldots, p_n$, and monitored region $R_i$, and energy supply $b_i$ for each sensor.
- **Find**: a *monitoring schedule* $(C_1, t_1), \ldots, (C_k, t_k)$ with the maximum length $t_1 + \ldots + t_k$, such that for any sensor $p_i$ the total active time does not exceed $b_i$. 

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Example of Maximum Sensor Network Lifetime Problem

Advantage of switching between sensor covers:

Non-disjoint set covers:
— the schedule $\{(p_1, p_2), 1\}, \{(p_2, p_3), 1\}, \{(p_3, p_1)\}, 1$;
— 3 units of time.

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CONTINUOUS AND EVENT-DRIVEN SENSOR NETWORK MODEL

• Given the regions which are required to monitor (or, in general, set of required targets)
• sensors who can monitor these targets
• energy supply
• energy consumption
• rate for monitoring
• listening and idle modes
• energy consumption for receiving and transmitting a package

• we explore the problem of maximizing sensor network lifetime

• sensors can interchange idle and active modes both for monitoring and communicating.
CONTINUOUS AND EVENT-DRIVEN SENSOR NETWORK MODEL

Communication and Monitoring Models

- Each sensor can be in the following communication modes:
  - sleeping,
  - listening,
  - receiving and
  - sending.
- and two monitoring modes:
  - idle and
  - active.

- The set of sensors largely exceeds the necessary amount to monitor $R$

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(DEEPS) Deterministic Energy-Efficient Protocol for Sensor networks target-monitoring protocol, system lifetime increase in 2 times!!!

full-fledged simulation of the monitoring protocols on NS2 combined with LEACH as a communication protocol

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Cluster-Based Communication

A Simple Algorithm

The problem: Select j cluster-heads of N nodes without communication among the nodes

The simplest solution:
- Each node determines a random number x between 0 and 1
- If $x < j / N \Rightarrow$ node becomes cluster-head

...it's good, but:

Cluster-heads dissipate much more energy than non cluster-heads!

How to distribute energy consumption?

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LEACH Communication Protocol

Low-Energy Adaptive Clustering Hierarchy

- Cluster-based communication protocol for sensor networks, developed at MIT
- Adaptive, self-configuring cluster formation

- The operation of LEACH is divided into rounds
- During each round a different set of nodes are cluster-heads
- Each node \( n \) determines a random number \( x \) between 0 and 1
- If \( x < T(n) \) \( \rightarrow \) node becomes cluster-head for current round
(LBP) Load-Balancing Protocol for Sensing

(1) \textit{(on-rule)}
whenever a sensor $s$ has a target covered solely by itself (no alert- or on sensor covers it), $s$ switches itself on, i.e., changes its state to "on".

(2) \textit{(off-rule)}
whenever each target covered by a sensor $s$ is also covered either by an on sensor or an alert-sensor with a larger battery supply, $s$ switches itself on, i.e., $s$ changes its state to "off".

Each global reshuffle of LBP needs 2 broadcasts (to the neighbors) from each sensor and the resulted set of all active sensors form a minimal sensor cover.

The LBP is a reliable protocol.
(LBP) Bottleneck

- LBP time schedule is twice shorter since it uses the 1000-battery sensors simultaneously for 999 time units
Deterministic Energy-Efficient Protocol for Sensing

Algorithm

(1) (on-rule)
whenever a sensor $s$ has a target covered solely by itself (no alert-or onsensor covers it), $s$ switches itself on, i.e., changes its state to "on".

(2) (off-rule)
whenever a sensor $s$ is not in charge of any target except those already covered by on-sensors, $s$ switches itself off, i.e., changes its state to "off".

DEEPS is a reliable protocol. Each global reshuffle of DEEPS needs 2 broadcasts (to the 2-neighbors) from each sensor and the resulted set of all active sensors form a minimal sensor cover.
An example of reliability violation (circles are sensors and rectangles are targets, numbers correspond to battery supply). 3 lower sensors have 3 batteries each and the 3 uppers sensors have 2 batteries each. Therefore, 3 lower targets are sinks with 5 batteries each. The upper target will be abandoned if all three upper poorer sensors will be switched off simultaneously.
NS2+LEACH Monitoring Simulations

Environment: NS2 – Network Simulator

LEACH communication protocol

DEEPS - Deterministic Energy-Efficient Protocol for Sensing

LBP – Load-Balancing Protocol for Sensing

1-DEEPS which is DEEPS but with a single reshuffle and local reparation on node die

EUPS - Energy Unaware Protocol for Sensing – where all sensors continuously monitor their targets
Simulation Results

Results which are represented in this presentation are obtained for 3 scenarios:

**Scenario-1:**
- Square territory $100m \times 100m$ which is divided into the small square faces $1m \times 1m$, and each face is considered like a target with coordinates equals with the middle of the face.
- 10,000 targets – good approximation for real area.
- Random distribution of sensors
- Faces are covered by one or more sensors, sensing radius is 5m.

**Scenario-2:**
- Random distribution of 100,000 targets in $100m \times 200m$.
- All others are the same as in Scenario-3

**Scenario-3:**
- The same as Scenario-1, with additional restriction: All faces are covered by at least 3 sensors.

Experimental results are for constant initial energy distribution 4(J) or random between 1 and 4(J).
Scenario-1

Number of active sensors

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Scenario-1

Covered area %

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Scenario-3 TARGET

Targets covered %

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Scenario-1

Covered area for different # of reshuffles

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Scenario-1

Number of sensors alive %
Scenario-1

Total energy consumption (J)

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