Wireless Sensor Networks
A survey on maximizing lifetime in sensor coverage problems

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Overview

Applications
Overview

Applications

Problem & variants

Mathematics

Maximize: \( t_1 + t_2 + t_3 + t_4 \)

\[
E_b t_1 + E_b t_2 + E_b t_3 + E_b t_4 \leq \beta \\
E_b t_1 + E_b t_2 + E_b t_3 + E_b t_4 \leq \beta \\
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E_b t_1 + E_b t_2 + E_b t_3 + E_b t_4 \leq \beta \\
t_j \geq 0 \quad \forall j | C_j \in \Omega
\]
Introduction to Wireless Sensor Networks
- Motivations
- Applications
- Wireless sensors
- Networks
- Objective functions
Research fundings

Funding is continuously growing

→ US Military $1.5B (on RTLS)
→ Living PlanIT $13T (10 years)

WSN market

<table>
<thead>
<tr>
<th></th>
<th>2012</th>
<th>2022</th>
<th>2032</th>
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<tbody>
<tr>
<td>Value</td>
<td>$0.6B</td>
<td>$2.4B</td>
<td>$6.5B</td>
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A wireless sensor network (WSN) consists of spatially distributed autonomous sensors to cooperatively monitor physical or environmental conditions, such as temperature, vibration, pressure or pollutants.

- Military applications
- Environment and civil engineering
- Industry and commerce
- Smart home
- Health
Military applications

Submarine movements
Military applications

Submarine movements

Battlefield surveillance
Military applications

Submarine movements

Battlefield surveillance

Enemy intrusion
Military applications

Submarine movements

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Military applications

Submarine movements

Battlefield surveillance

Enemy intrusion
Military applications (sensors)
Military applications (sensors)
Forest fire detection
Environment and civil engineering

Forest fire detection

Volcano eruption prevention

1) Earthquake or eruption occurs
2) Nodes detect seismic event
3) Each node sends event report to base station

GPS receiver for time sync
Base station at observatory
FreeWave radio modem

Long-distance radio link (4km)
Environment and civil engineering

Forest fire detection

Volcano eruption prevention

Land slide early detection

*Active waveguide with sensor attached*

- Transducer
- Steel waveguide
- Gravel backfill
- Deforming slope generates acoustic emission from gravel

*GPS receiver for time sync*

Base station at observatory
Environment and civil engineering

Forest fire detection

Volcano eruption prevention

Land slide early detection

Bridge/Tunnel/Highway monitoring
Environment and civil engineering

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Bridge/Tunnel/Highway monitoring
Monitoring security elements
Monitoring security elements

Sensors in cities
Industry and commerce

Monitoring security elements

Sensors in cities

Inventory (RFID)
Smart home

Intrusion alarm
Smart home

Intrusion alarm

Fire/gaz detectors
Smart home

Intrusion alarm

Fire/gaz detectors

Smart energy/passive house

Network of wireless energy meters and actuators connected to home/office appliances.

Energy management station and user interface.

"Smart" energy meter provides real-time energy price.
Smart home

Intrusion alarm

Fire/gaz detectors

Smart energy/passive house

Connected objects

ARCHOS Smart Home
Connectez votre maison facilement. Sans câbles - Miniaturisés

Smart Home Tablet

Marc Sevaux (UBS)
Smart home

- Intrusion alarm
- Fire/gaz detectors
- Smart energy/passive house
- Connected objects
Body embedded sensors
Health

Body embedded sensors

Sensors for sports

ANALYZE YOUR SWING
IMPROVE YOUR GAME

ZEPP BASEBALL ▶️ ZEPP GOLF ▶️ ZEPP TENNIS ▶️
Health

Body embedded sensors

Sensors for sports
Health

Body embedded sensors

Sensors for sports

![Image of sensors for sports]
Health

Body embedded sensors

Sensors for sports

Artery exploration
Health

Body embedded sensors

Sensors for sports

Artery exploration

Disable people
Electronic device:
- sensing module
- short-range communication
- self powered
- limited processing capabilities
Many types of wireless sensors
Many types of wireless sensors
Many types of wireless sensors
Different types of networks

Random network
Different types of networks

Mesh 2D regular
Different types of networks

Hexagon regular
Different types of networks

Star

![Star Network Diagram]
Different types of networks

Ring
Different types of networks

Ring-star
Different types of networks

Ad-hoc
Objective functions

- **Minimization** of the covering breach
- **Minimization** of energy consumption
- **Minimization** of deployment cost
- **Maximization** of area monitoring
- **Maximization** of the network lifetime
Problem and variants

- Our case study
- MNLB
- Classical variants of the problem
In a specific area
In a specific area
- a set of targets to monitor over time
In a specific area

- a set of **targets** to monitor over time
- a set of **sensors** to cover the targets
In a specific area
- a set of **targets** to monitor over time
- a set of **sensors** to cover the targets
- a sensor maximum **range** for detection
Wireless sensors are [randomly] deployed for covering the set of targets

- all sensors are identical
- they operate on a battery, whose lifetime is normalized to one
- when a sensor is \textbf{inactive}, it consumes no energy
- when a sensor is \textbf{active}, it covers all the targets under its sensing range $R_s$
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$s_1$ covers $t_1$ and $t_2$ when it is active
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$s_1$ covers $t_1$ and $t_2$ when it is active

when $s_1$ and $s_2$ are active, they cover all the targets
What we are looking for!

Initial situation
What we are looking for!

Not Good
What we are looking for!

Good
What we are looking for!

Good
What we are looking for!

Almost Good
What we are looking for!

Very Good!!!
Maximization of the Network Lifetime under Bandwidth constraints

- the network lifetime is the objective to maximize
- all targets should be covered at any time
- bandwidth constraint is modeled as follows: any subset of active sensors must be made of at most $W$ sensors
Lifetime maximization: MNLB

- all targets are covered
- if the bandwidth constraint is $W = 5$, ok
- we have to find other similar subsets to maximize lifetime
Lifetime maximization: MNLB

C. Wang, M.T. Thai, Y. Li, F. Wang, and W. Wu

- 01-LP
- Relaxed 01-LP
- Heuristics

- First to solve MNLB
- MNLB \( \mathcal{NP} \)-complete
- Solve relaxed MCBB
- Transform into MNLB
- Heuristic approach
- 4 instances only
- 50 sensors
Maximization of the Network Lifetime with $Q$-coverage constraint

- the network lifetime is the objective to maximize
- all targets should be covered by $Q$ sensors at any time
Lifetime maximization: $Q$-coverage

- all targets are now covered by $Q$ sensors at any time ($Q = 1$)
all targets are now covered by $Q$ sensors at any time ($Q = 2$)

we have to find plenty of similar subsets to maximize lifetime
Y. Gu, H. Liu, and B. Zhao.
Target coverage with QoS requirements in wireless sensor networks.

- $Q$-coverage $NP$-complete
- exact approach
- efforts on initial columns
- results on small instances
- 30-75 sensors
- only compare to MNLB ($Q = 1$)
Maximization of the Network Lifetime with connectivity constraint

- the network lifetime is the objective to maximize
- all targets should be covered at any time
- all activated targets should be connected to a base station
all targets are covered by a sensor, when activated
all targets are covered by a sensor, when activated

a base station is present in the network
Lifetime maximization: base station

- All targets are covered by a sensor, when activated.
- A base station is present in the network.
- Every sensor has a large communication range.
all targets are covered by a sensor, when activated
- a base station is present in the network
- every sensor has a large communication range
- all activated sensors should be connected to the base station
all targets are covered by a sensor, when activated

a base station is present in the network

every sensor has a large communication range

all activated sensors should be connected to the base station
M. Gentili and A. Raiconi.

$\alpha$-Coverage to extend network lifetime on wireless sensor networks.


- Column generation
- Heuristics

- exact approach
- greedy heuristics
- test bench 480 instances
- 25-150 sensors
- can solve $\alpha$-coverage
Maximization of the Network Lifetime with adjustable sensing range

- the network lifetime is the objective to maximize
- all targets should be covered at any time
- sensing range can be adjusted to reduce energy consumption
  - ad-hoc sensing ranges
  - predefined sensing ranges
all targets are covered by a sensor, when activated
Lifetime maximization: adjustable sensing range

- all targets are covered by a sensor, when activated
- but the sensing range is reduced to the minimum value for covering the same targets and saving energy
Lifetime maximization: adjustable sensing range

M. Cardei, J. Wu, M. Lu, and M.O. Pervaiz.
Maximum network lifetime in WSN with adjustable sensing ranges
*Wireless And Mobile Computing, Networking And Communications*, 438–445, 2005

- 01-LP
- Relax. LP heuristics
- Heuristics

- Nice study on sensing ranges
- Only 16 instances
- 25-250 sensors
Lifetime maximization: $\alpha$-coverage

- sensors and targets are randomly placed
Lifetime maximization: $\alpha$-coverage

- sensors and targets are randomly placed
- a fraction $\alpha$ of the targets are not covered
- here, $\alpha = 4/30 = 0.13$
Lifetime maximization: trade-off

A decision maker can choose between lifetime and $\alpha$.

200 sensors, 120 targets.
Omnidirectional sensor

Decide when to set the sensor to active state
Lifetime maximization: directional sensors and focal lens

Omnidirectional sensor    Directional sensor

Decide when to set the sensor to active state

Set working direction $\theta$
Lifetime maximization: directional sensors and focal lens

Omnidirectional sensor

Directional sensor

Camera sensor

Decide when to set the sensor to active state

Set working direction $\theta$

Set focal distance $s$