Energy-Efficient Target Coverage in Wireless Sensor Networks

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Outline

♦ Introduction
♦ Related Work
♦ Target Coverage Problem
♦ Solutions to Compute Maximum Set Covers
♦ Simulation
♦ Conclusion
Introduction

- Application of sensor networks
  - National security
  - Surveillance
  - Health care
  - Environment monitoring

- A critical issue in wireless sensor networks
  - Power scarcity
  - Transmit: 0.38w~0.7w, Receive: 0.36w
  - Idle: 0.34w, Sleep: 0.03w
  - Communication/computation power usage ratio >1000

Power saving techniques can generally be classified in the following categories:

- Schedule the wireless nodes to alternate between active and sleep mode.
- Power control by adjusting the transmission range of wireless nodes.
- Energy efficient routing, data gathering.
- Reduce the amount of data transmitted and avoid useless activity.
Related Work

♦ The coverage problems can be classified
  ✓ Area coverage
  ✓ Point (or target) coverage

♦ Cardei and Du [2]
  ✓ Disjoint sensor sets (disjoint set covers)
  ✓ every cover completely monitor all the target points

Related Work (cont.)
Target Coverage Problem

♦ Targets: know location, need to be continuously observed
♦ Sensors: a large number of sensors randomly deployed closed to the targets
♦ Basic station: a central data collector node
♦ In order to enlarge the lifetime
  – Sensor nodes have two states
    • Active or Sleep
  – Sensors send their location information to the BS
  – BS executes the sensor scheduling algorithm
  – and broadcast the schedule to all sensors
Definition: target coverage problem

- $m$ targets know location
- $n$ sensors randomly are deployed
- Schedule the sensor nodes activity
  - Such that all the targets are covered
- Maximum the network lifetime
- Lifetime of each sensor: $[0, 1]$
Maximum Set Covers (MSC)

- All sensors are active continuously
  - Network lifetime
    - 1
Maximum Set Covers (MSC)

- Cardei and Du [2]
  - $S_1 = \{s_1, s_2\} = 1$
  - $S_2 = \{s_3, s_4\} = 1$
  - Network lifetime
    - $1+1=2$
Every sensor is part of more than one set
- $S_1 = \{s_1, s_2\} = 0.5$
- $S_2 = \{s_2, s_3\} = 0.5$
- $S_3 = \{s_1, s_3\} = 0.5$
- $S_4 = \{s_4\} = 1$
- Network lifetime
  - $0.5 + 0.5 + 0.5 + 1 = 2.5$
Solutions to Compute Maximum Set Covers

♦ Two heuristics for the MSC problem
  ✔ Linear Programming based heuristic 
    \textit{(LP-MSC Heuristic)}
  ✔ Greedy heuristic 
    \textit{(Greedy-MSC Heuristic)}
Solutions to Compute Maximum Set Covers

♦ LP-MSC Heuristic
  – Model the MSC problem as an Integer Programming
  – use the relaxation technique to design a Linear Programming based heuristic
**Solutions to Compute Maximum Set Covers**

**Greedy-MSC Heuristic (C, R, w)**

1: set lifetime of each sensor to 1  
2: SENSORS = C  
3: i = 0  
4: while each target is covered by at least one sensor in SENSORS do  
5: /\* a new set cover C_i will be formed \*/  
6: i = i + 1  
7: C_i = 0  
8: TARGETS = R  
9: while TARGETS ≠ 0 do  
10: /\* more targets have to be covered \*/  
11: find a critical target r_critical ∈ TARGETS  
12: select a sensor s_u ∈ SENSORS with greatest contribution, that covers r_critical  
13: C_i = C_i ∪ s_u  
14: for all targets r_k ∈ TARGETS do  
15: if r_k is covered by s_u then  
16: TARGETS = TARGETS - r_k  
17: end if  
18: end for  
19: end while  
20: for all sensors s_j ∈ C_i do  
21: lifetime_s_j = lifetime_s_j - w  
22: if lifetime_s_j == 0 then  
23: SENSORS = SENSORS - s_j  
24: end if  
25: end for  
26: end while  
27: return i-number of set covers and the set covers C_1, C_2, ..., C_i
Solutions to Compute Maximum Set Covers

\[ C = \{s_1, s_2, s_3\} \]
\[ R = \{r_1, r_2, r_3\} \]
\[ W=0.1 \]
\[ r_1 \text{ can be covered by } s_2 \text{ and } s_3 \]

Select \( s_1 \)
\( s_1 \) also covers \( r_2 \)
Now, we can select \( s_2 \) or \( s_3 \) to cover \( r_3 \)

Select \( s_2 \)
\( \text{lifetime}_{s1} = \text{lifetime}_{s1} - W \)
\( \text{lifetime}_{s2} = \text{lifetime}_{s2} - W \)
Simulation

- 500m * 500m area
- Number of sensor nodes: 25~75
- Number of targets: 5~15
- The sensing range: 100~300 m
Simulation

the sensing range is 250m
Simulation

10 targets randomly deployed

More sensing range, more power consumption ??
## Simulation

<table>
<thead>
<tr>
<th>Sensors</th>
<th>LP-MSC</th>
<th>Greedy-MSC</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Lifetime</td>
<td>Runtime (s)</td>
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<tr>
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<td>75</td>
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</tbody>
</table>
Conclusion

♦ Maximum the network lifetime of the target coverage problem
  – By organizing the sensor nodes in non-disjoint set covers

♦ Propose two efficient heuristics
  – Linear Programming formulation
  – Greedy approach
    • Low running time
    • Is more scalable to large sensor networks
Thank you
Integer Programming Formulation of the MSC Problem

Maximize  \( t_1 + \ldots + t_p \)

subject to  \( \sum_{j=1}^{p} y_{ij} \leq T_i \) for all \( s_i \in C \)

\[ \sum_{i \in C_k} y_{ij} \geq t_j \] for all \( r_k \in R, j = 1, \ldots, p \)

where  \( 0 \leq y_{ij} \leq t_j \leq 1 \)

a set of \( n \) sensor nodes \( C = \{ s_1, s_2, \ldots, s_n \} \)
a set of \( m \) targets \( R = \{ r_1, r_2, \ldots, r_m \} \)

Let us set a bound \( p \) for the number of set-covers

\( C_k = \{ i \mid \text{sensor } s_i \text{ covers target } r_k \} \)

\( x_{ij} \), boolean variable, for \( i = 1..n \) and \( j = 1..p \);
\( x_{ij} = 1 \) if sensor \( s_i \) is in the set cover \( S_j \), otherwise \( x_{ij} = 0 \).

\( t_j \in \mathbb{R}, 0 \leq t_j \leq 1 \), for \( j = 1..p \), represents the time allocated for the set cover \( S_j \).

\( y_{ij} = x_{ij} t_j \)
**LP-MSC Heuristic**

**Step 1** Solve the linear programming LP formulated above. Let \((y_{ij}^*, t_j^*), i = 1..n \text{ and } j = 1..p\), be the optimal solution of the LP. Set the network lifetime \(C = 0\).

**Step 2** The first approximation solution can be obtained as follows:

```plaintext
for all \( j = 1 \text{ to } p \) do
  set \( y_{ij}^0 = 0 \) for all sensors \( s_i \in C \)
  set \( t_j^0 = \min_k \max_{i \in C_k} y_{ij}^* \)
  for all \( k = 1 \text{ to } m \) do
    / * for each \( r_k \in R \) */
    choose an \( i \in C_k \) such that \( y_{ij}^* \geq t_j^0 \) and set
    \( y_{ij}^0 = t_j^0 \)
  end for
end for
```

**Step 3** We iteratively repeat step 1 and step 2.