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 [14]
    idle 0.34w sleep 0.03w
  - ☑ communication/computation power usage ratio >1000

[14] V. Raghunathan, C. Schurgers, S. Park, and M. B. Srivastava, Energy-Aware Wireless Microsensor Networks, IEEE Signal Processing Magazine, 19 (2002), pp 40-50.

Introduction (cont.)

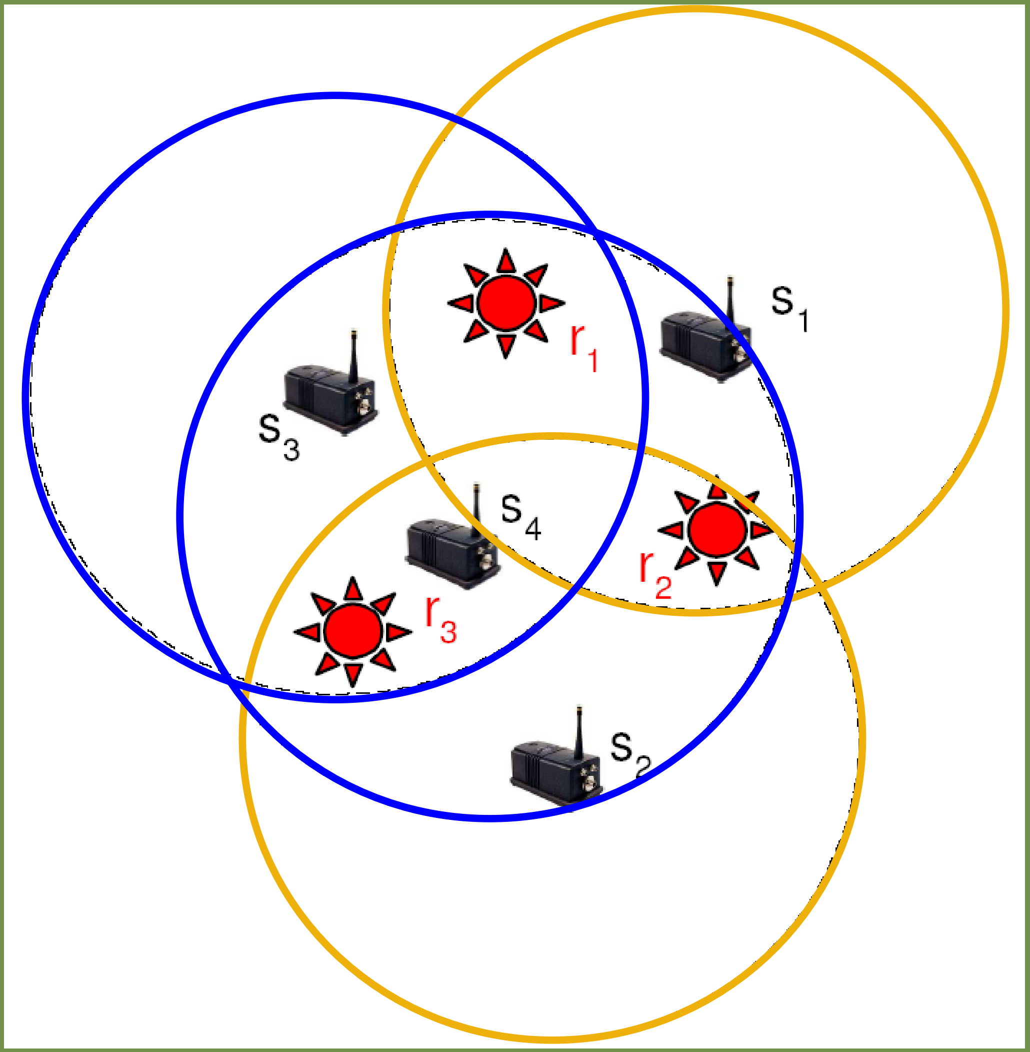
- Power saving techniques can generally be classified in the following categories
  - ☑schedule the wireless nodes to alternate between active and sleep mode
  - ☑power control by adjusting the transmission range of wireless nodes
  - ☑energy efficient routing, data gathering
  - ☑reduce the amount of 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

[2] M. Cardei, D.-Z. Du,
Improving Wireless Sensor Network Lifetime through Power Aware Organization, accepted to appear in ACM Wireless Networks..

Related Work (cont.)



Target Coverage Problem

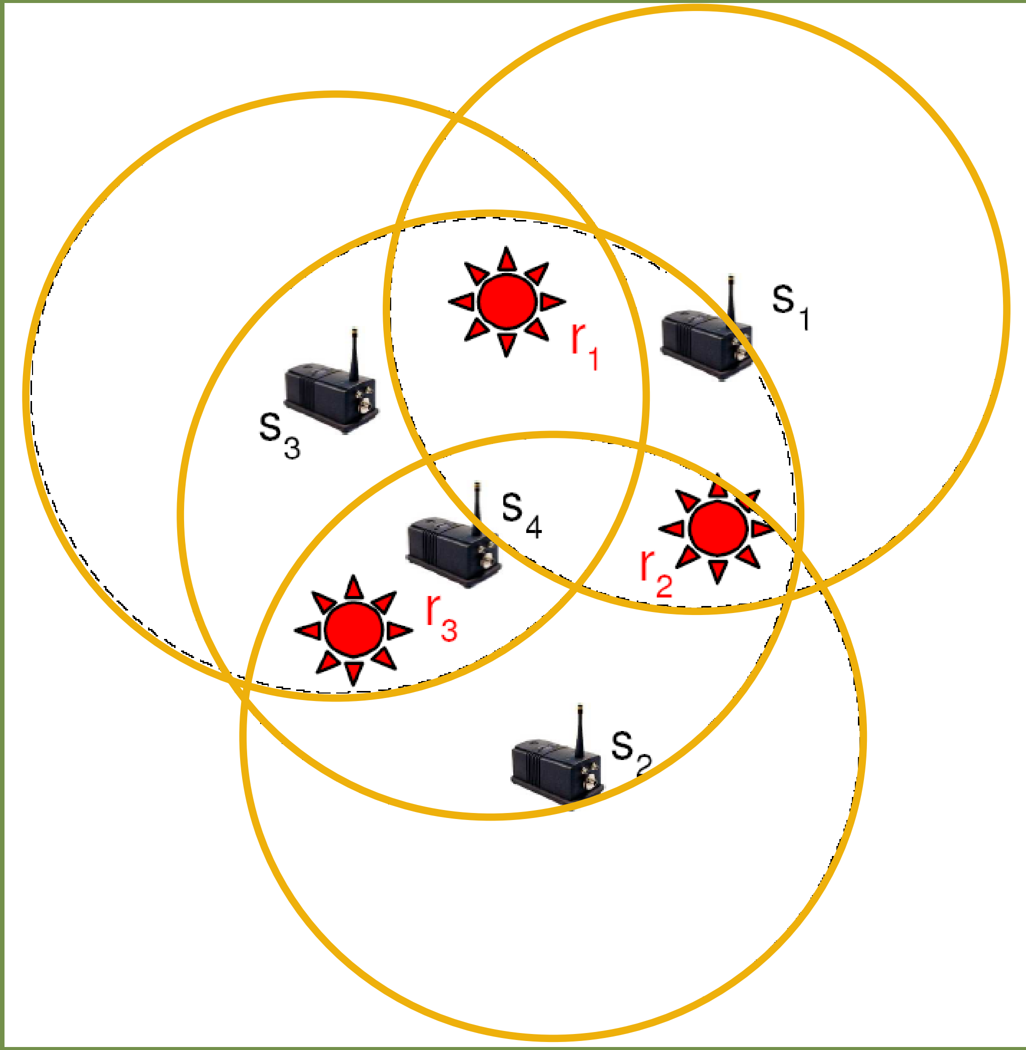
- Targets: know location, need to be continuously observed
- Sensors: a large number of sensors randomly deployed closed to the targets
- Basic station: a central data collector node
- In order to enlarge the lifetime
  - Sensor nodes have two states
    - Active or Sleep
  - Sensors send their location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

Maximum Set Covers (MSC)

- 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]

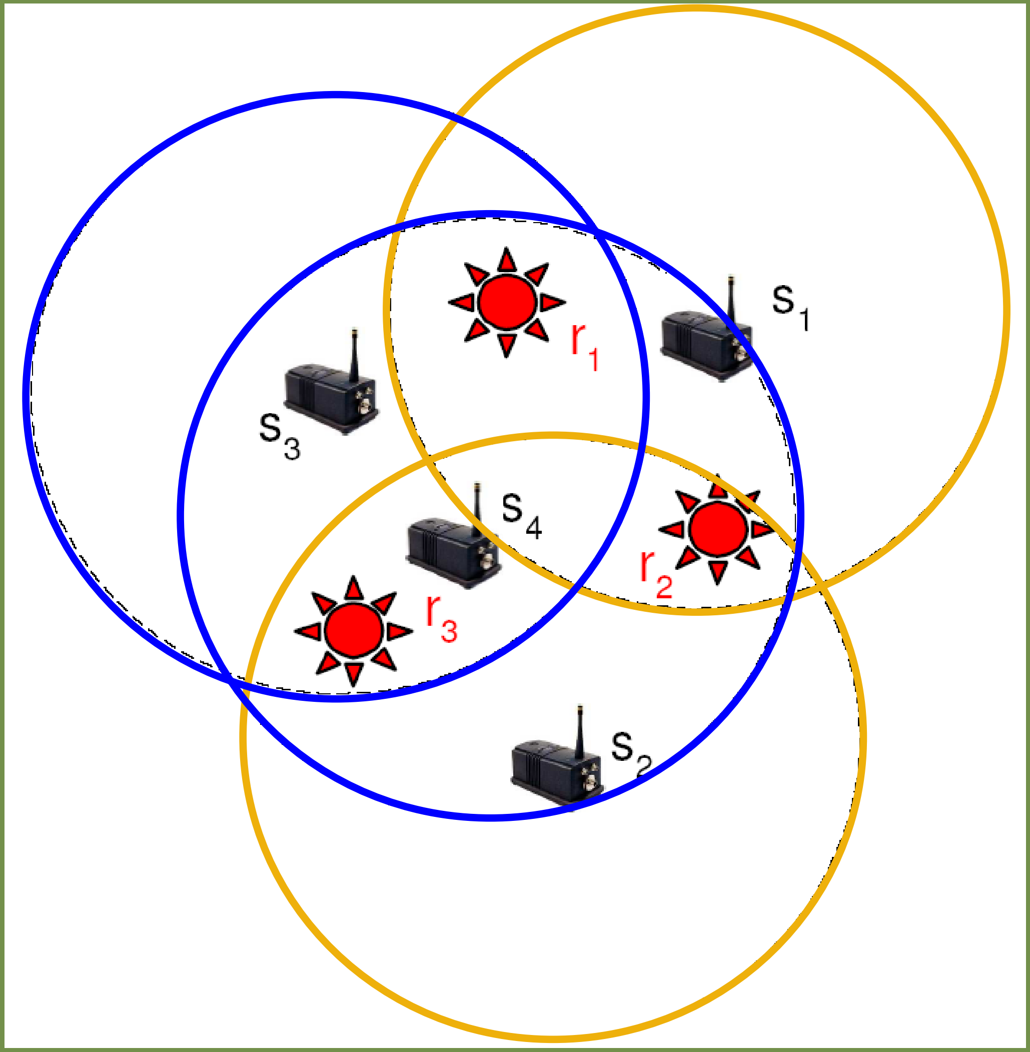
Maximum Set Covers (MSC)

- All sensor are active continuously
  - Network lifetime
    - 1



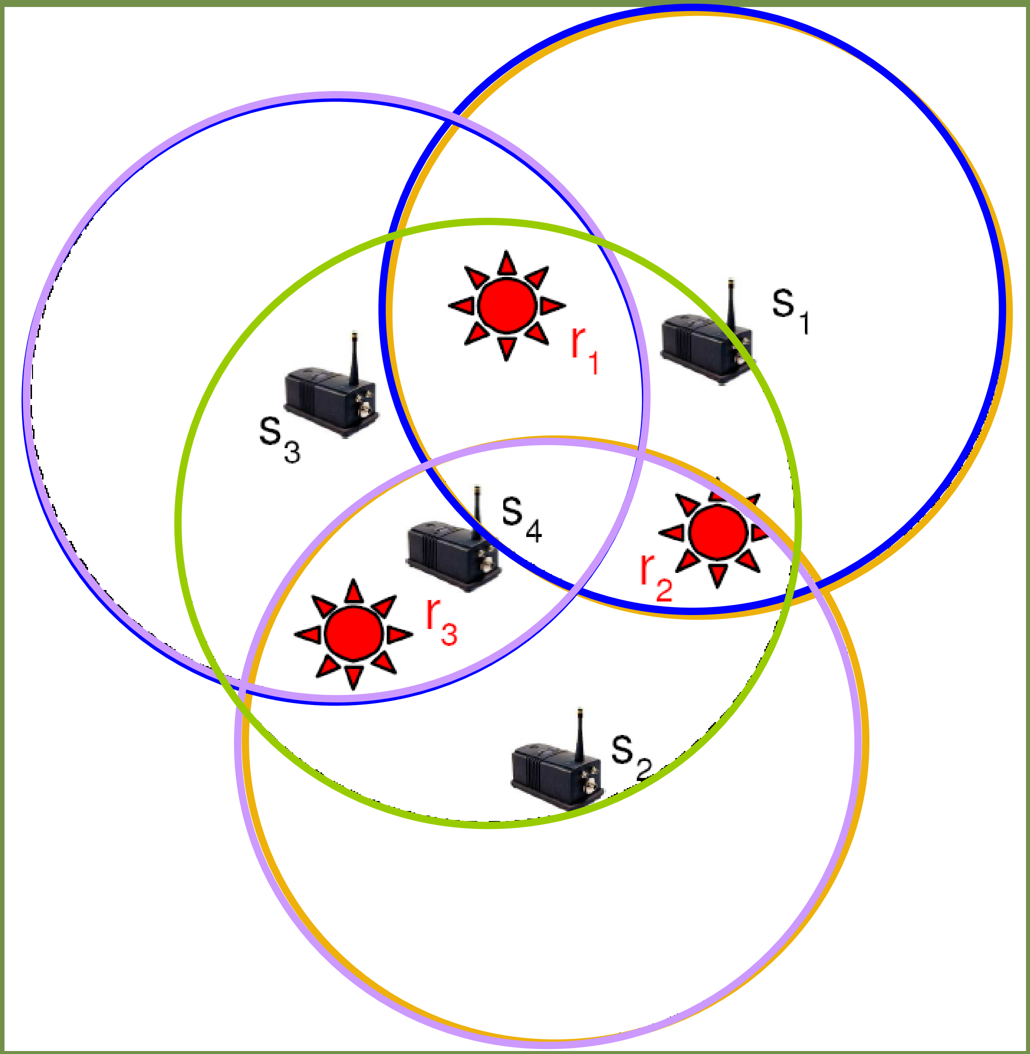
Maximum Set Covers (MSC)

- Cardei and Du [2]
  - $S_1 = \{s_1, s_2\} = 1$
  - $S_2 = \{s_3, s_4\} = 1$
  - Network lifetime
    - 1+1=2



Maximum Set Covers (MSC)

- 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 (*LP-MSC Heuristic)*
  - ☑ Greedy heuristic (*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)

set lifetime of each sensor to 1
SENSORS = C
i=0
while each target is covered by at least one sensor in SENSORS **do**
  /* a new set cover C_i will be formed */
  i = i + 1
  $C_i = \emptyset$
  TARGETS = R
  while TARGETS $\neq \emptyset$ **do**
    /* more targets have to be covered */
    find a critical target $r_{critical} \in TARGETS$
    select a sensor $s_u \in SENSORS$ with greatest contribution, that covers $r_{critical}$
    $C_i = C_i \cup s_u$
    for all targets $r_k \in TARGETS$ **do**
      if r_k is covered by s_u **then**
        $TARGETS = TARGETS - r_k$
      end if
    end for
  end while
  for all sensors $s_j \in C_i$ **do**
    lifetime_s_j = lifetime_$s_j - w$
    if lifetime_s_j == 0 **then**
      SENSORS = SENSORS - s_j
    end if
  end for
end while
return i-number of set covers and the set covers C_1, C_2, ..., C_i

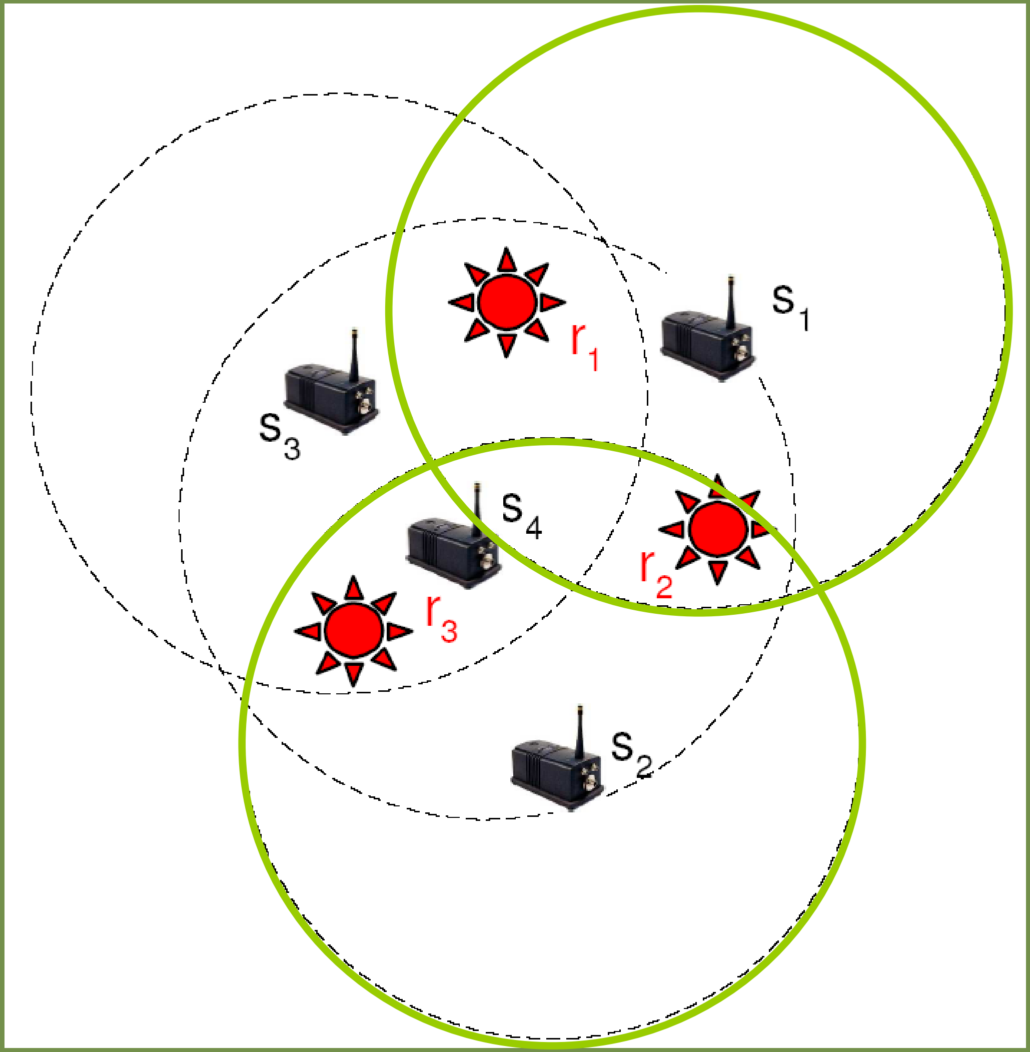
Solutions to Compute Maximum Set Covers

C = {s1 , s2 , s3}
R = {r1 , r2 , r3}
W=0.1
r1 can be covered by
s2 and s3

Select s1
s1 also covers r2
Now, we can select s2 or s3
to cover r3

Select s2

lifetime_s1 = lifetime_s1 – W
lifetime_s2 = lifetime_s2 – W

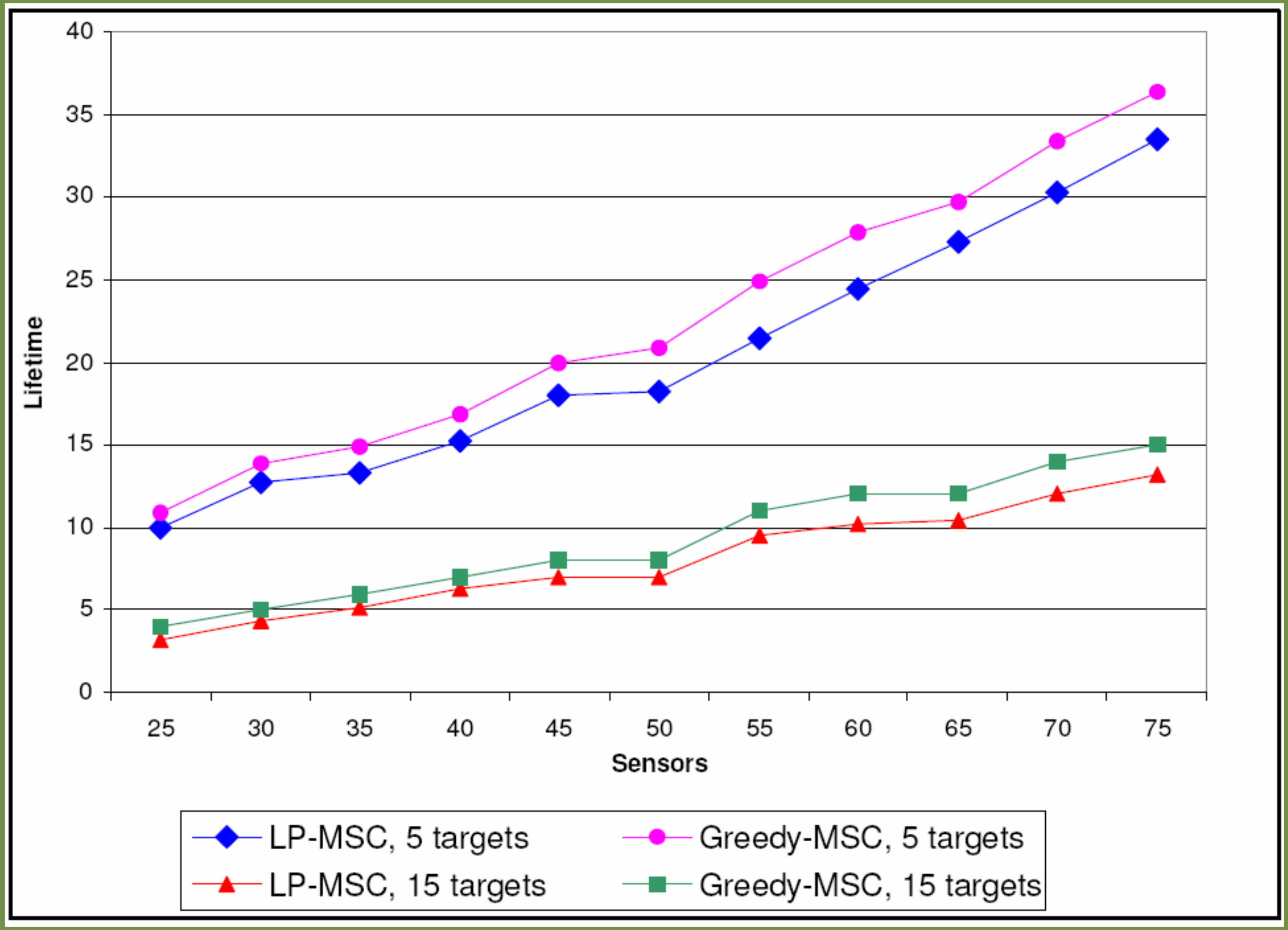


Simulation

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

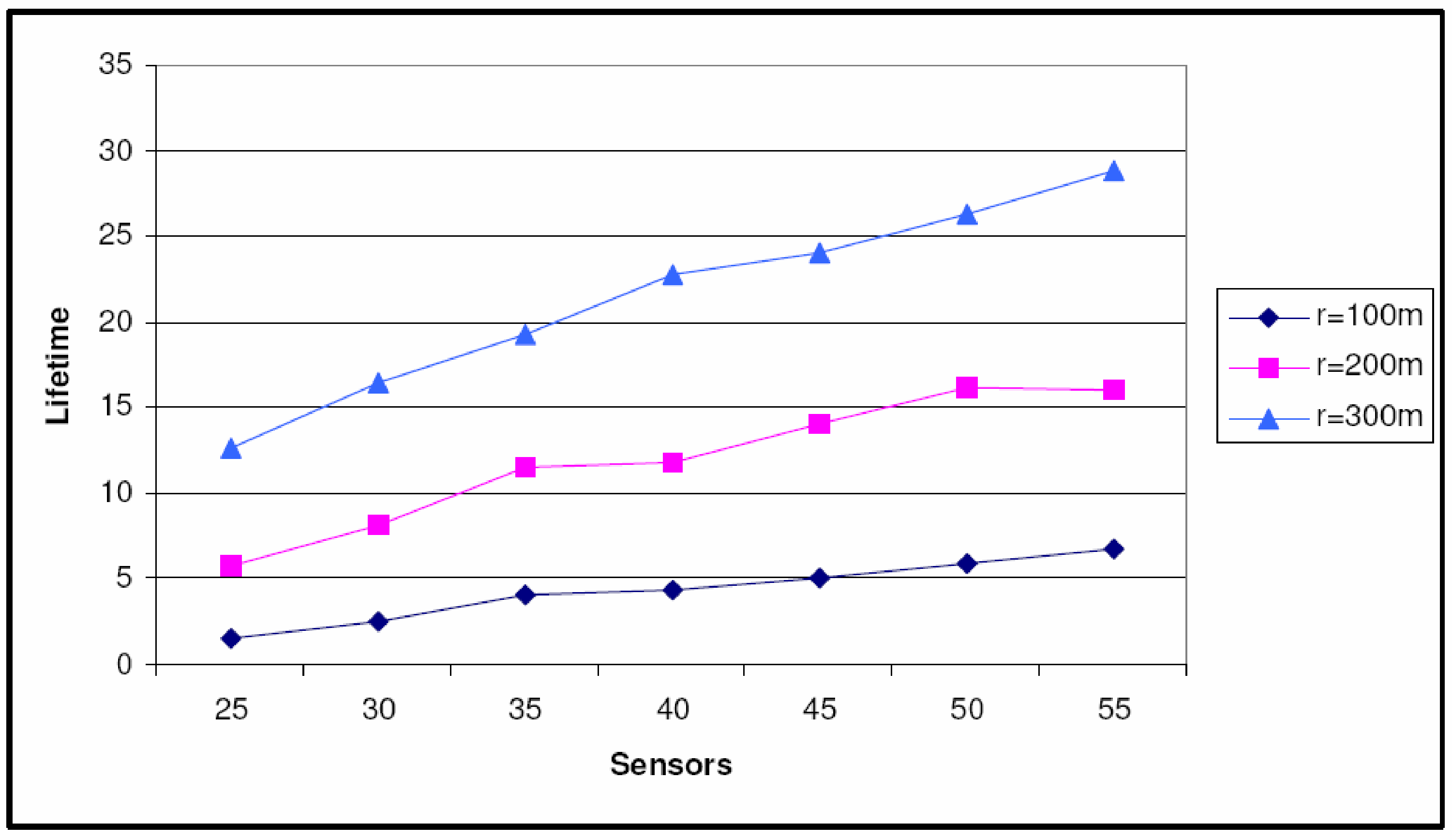
Simulation

the sensing range is 250m



Simulation

10 targets randomly deployed



More sensing range, more power consumption ??

Simulation

Sensors	LP-MSC		Greedy-MSC	
	Lifetime	Runtime (s)	Lifetime	Runtime (s)
25	10.004	12.428	10.900	0.100
30	12.715	24.235	13.900	0.150
35	13.320	32.237	14.900	0.150
40	15.293	52.886	16.900	0.290
45	17.957	127.843	19.900	0.331
50	18.236	220.738	20.900	0.450
55	21.405	334.361	24.900	0.620
60	24.456	511.095	27.800	0.631
65	27.318	3262.181	29.700	0.851
70	30.260	11789.452	33.400	0.871
75	33.410	2976.460	36.300	1.202

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 $t_1 + ... + t_p$

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 $r_k \in R, j = 1, .., p$

where $0 \leq y_{ij} \leq t_j \leq 1$

a set of n sensor nodes $C = \{s_1, s_2, ..., s_n\}$

a set of m targets $R = \{r_1, r_2, ..., r_m\}$

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 $x_{ij} = 0$.

$t_j \in \Re$, $0 \leq t_j \leq 1$, 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), $i = 1..n$ and $j = 1..p$, be the optimal solution of the LP. Set the network lifetime $G = 0$.

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

for all j = 1 to p **do**
  set $y^0_{ij} = 0$ for all sensors $s_i \in C$
  set $t^0_j = \min_k \max_{i \in C_k} \ y^*_{ij}$
  for all k = 1 to m **do**
    $/* \ for \ each \ r_k \in R \ */$
    choose an $i \in C_k$ such that $y^*_{ij} \geq t^0_j$ and set $y^0_{ij} = t^0_j$
  end for
end for

Step 3 We iteratively repeat step 1 and step 2