Minimum Coverage Breach and Maximum Network Lifetime in Wireless Sensor Networks

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Outline

- Coverage Model with Bandwidth Constraints
- Trade-off Scheme
- LP-relax Algorithm
- Greedy Heuristic
- Numerical Results

Wireless Sensor Network

- Main characteristic:
  - Limited energy
  - Redundancy
- QoS measurement:
  - Network Lifetime
  - Coverage

Single-hop Target Coverage Model

- Coverage Model
  - Target Model and Area Model
  - An area model can be converted into a target model
- Single-hop Target Coverage model
  - Setting:

    a set of sensors/targets, and “covering” relations between them
  - Approach: scheduling sensor nodes into subsets, each of which can cover all targets, and is alternatively activated to work
  - Goal: total lifetime is maximized

Bandwidth Constraint

- A major potential problem:
  - Not sufficient bandwidth for a subset of sensors to simultaneously send data
- Bandwidth Constraint:
  - time division scheme of single channel: #time slots
  - multiple channels scheme: #channels
  - Essentially, size of simultaneously active sensors
- When bandwidth is not sufficient
  - Some targets are covered, but others may not be. $ BREACH

Related Work

- Coverage breach issues due to bandwidth constraint is addressed by Cheng et al (05).
- Minimum Breach Problem
  - Divide sensors into p disjoint subsets $S_1, S_2, \ldots, S_p$, where $p=[n/W]$
  - Coverage breach is defined as

$$\sum_{j=1}^{p} (\#\text{ uncovered targets by } S_j)$$

- The use of disjoint subsets simplify the issues but may weaken the solution.

Measurement of Coverage Breach

- (Total) coverage breach:

$$\sum_{j=1}^{p} \sum_{k=1}^{m} (t_j - t_j z_{jk})$$

  z_{jk} =1 indicates at least one sensor in S_j can cover target r_k

- Breach Rate (BR)

$$BR = \frac{\sum_{j=1}^{p} \sum_{k=1}^{m} (t_j - t_j z_{jk})}{m \cdot \sum_{j=1}^{p} t_j}$$

Tradeoff

- In applications, totally coverage may not be necessary.
  - Minimize the coverage breach with a lower bound of NLT
  - Prolong NLT with an upper bound of coverage breach
- The longer network lifetime is gain, the more coverage breach may occur.
- A tradeoff between coverage breach and network lifetime
  - Two different models are proposed for the two scenarios above

Minimum Coverage Breach with Bandwidth Constraints (MCBB)

- Given:
  - Set of sensors $C=\{s_1, s_2,\ldots,s_n\}$
  - Set of targets $R=\{r_1,r_2,\ldots,r_m\}$
  - Coverage relation between C and R
  - Number of available channels W
  - Minimum required lifetime T_0
- Output a optimal schedule of sensors, $\{(S_1, t_1), (S_2,t_2), \ldots,(S_p,t_p)\}$, S_j» S, subject to:
  - Total coverage breach is minimized
  - total active time for each sensor doesn't exceed 1
  - Network lifetime is at least T_0
  - Size of each S_j is at most W

Minimum Coverage Breach with Bandwidth Constraints (MCBB)

- Comparison between the Minimum Breach problem
  - Non-disjoint subsets vs. Disjoint subsets
    - Smaller Breach rate may be achieved
  - Arbitrary total lifetime in (0,n] vs. Fixed total lifetime [n/W]

Maximum Network Lifetime with Bandwidth Constraints (MNLB)

- Given:
  - Set of sensors $C=\{s_1, s_2,\ldots,s_n\}$
  - Set of targets $R=\{r_1,r_2,\ldots,r_m\}$
  - Coverage relation between C and R
  - Number of available channels W
  - Max breach rate parameter α
- Output a schedule of sensors, $\{(S_1, t_1), (S_2,t_2), \ldots,(S_p,t_p)\}$, S_i» S, subject to:
  - Total network lifetime is maximized
  - total active time for each sensor doesn't exceed 1
  - Breach rate is at most α
  - Size of each S_j is at most W

Relation between MCBB and MNLB

- Strongly related with each other
  - Any algorithm for MCBB can be converted into an algorithm for MNLB using a binary search strategy and vice versa
- How to solve?
  - Both are NP-hard
  - Heuristics are proposed to solve MCBB

Heuristics for MCBB
— MSCMB: LP-relaxation algorithm

- An LP-relaxation algorithm
- Formulate MCBB into an Integer Linear Programming (IP)

A Integer Programming Formulation of MCBB

non-linear

Lifetime constraint for each sensor

Bandwidth Constraint

Total Lifetime Constraint

Replace $t_j z_{jk}$ with w_{jk}, and replace $x_{ij} t_j$ with y_{ij}

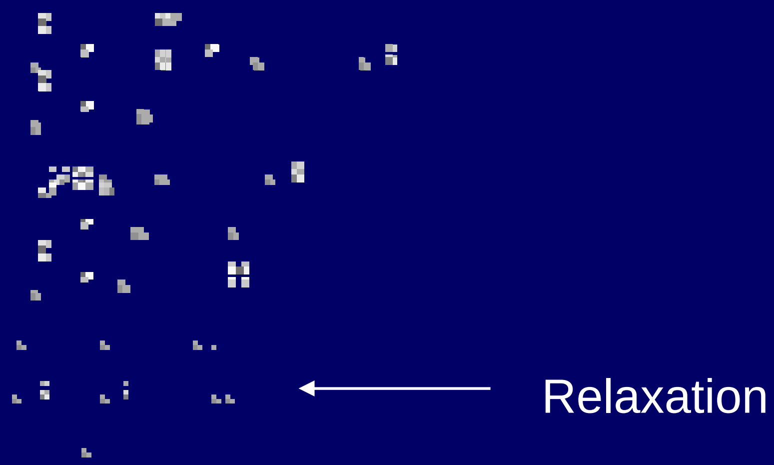
Integer Linear Programming Formulation

→ Lifetime constraint for each sensor

→ Bandwidth Constraint

→ Total Lifetime Constraint

Heuristics for MCBB
— MSCMB: LP-relaxation algorithm



Heuristics for MCBB
— MSCMB: LP-relaxation algorithm

- Step 0 : relax the integer constraints on y_{ij} and w_{jk} .
- Step 1 : Solve LP to get the optimal solution , and .
- Step 2 : Round y_{ij} and w_{jk} according to the optimal value.

Heuristics for MCBB
— Greedy-MSC algorithm

- Another heuristic based on greedy strategy are also proposed.
  - Step 0 : Set the time granularity $l=T_0/p$
  - Step 1 : Use greedy strategy to iteratively find subsets of sensors with the same time duration l.

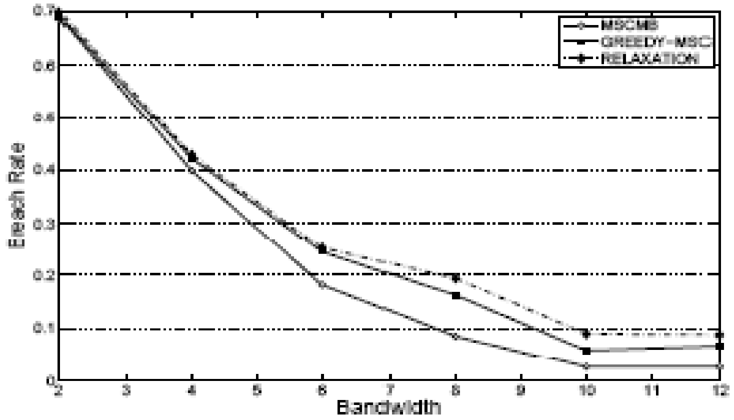
Heuristics for MNLB

- As we know, both MSCMB and Greedy-MSC algorithm can be used to solve MNLB.
  - MSCMB \$ MNLB-LP
  - Greedy-MSC \$ MNLB-Greedy

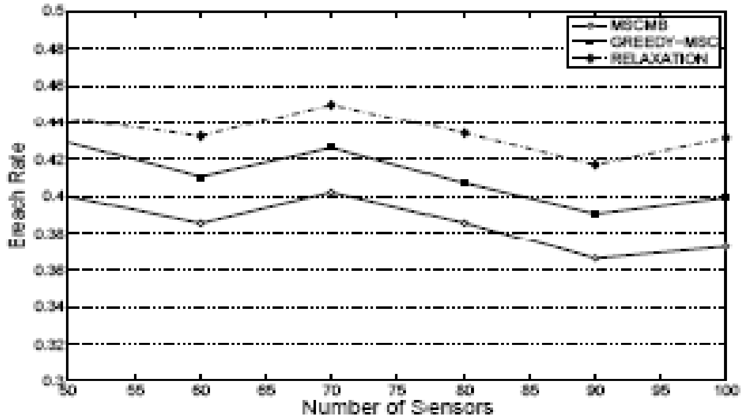
Experimental Performance

- Simulations for MCBB
  - Sensors and targets are uniformly deployed in a 500m by 500m area
  - Default parameters:
    - n = 50
    - m = 30
    - W = 4
    - Sensor range = 150m
    - $T_0 = [n/W]$ ——— for comparison

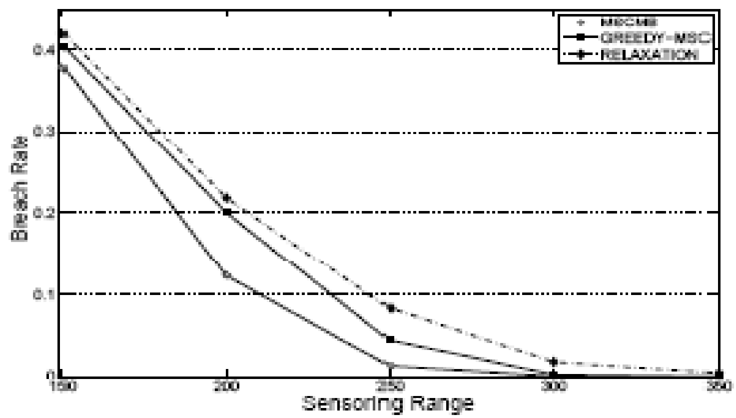
Experimental Performance



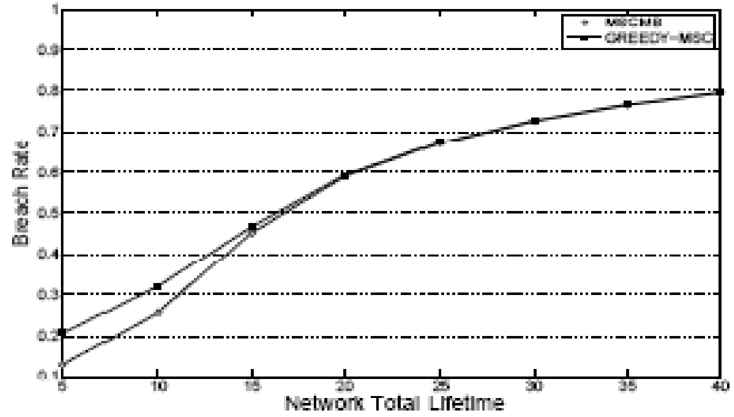
(a) Effect of Bandwidth Constraints



(b) Effect of Sensors Number



(c) Effect of Sensing Range

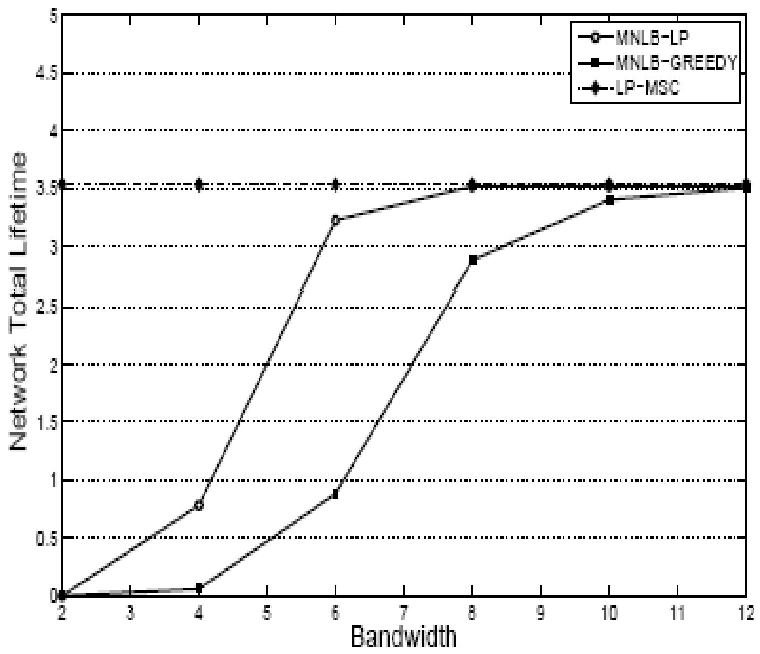


(d) Effect of Network Total Lifetime

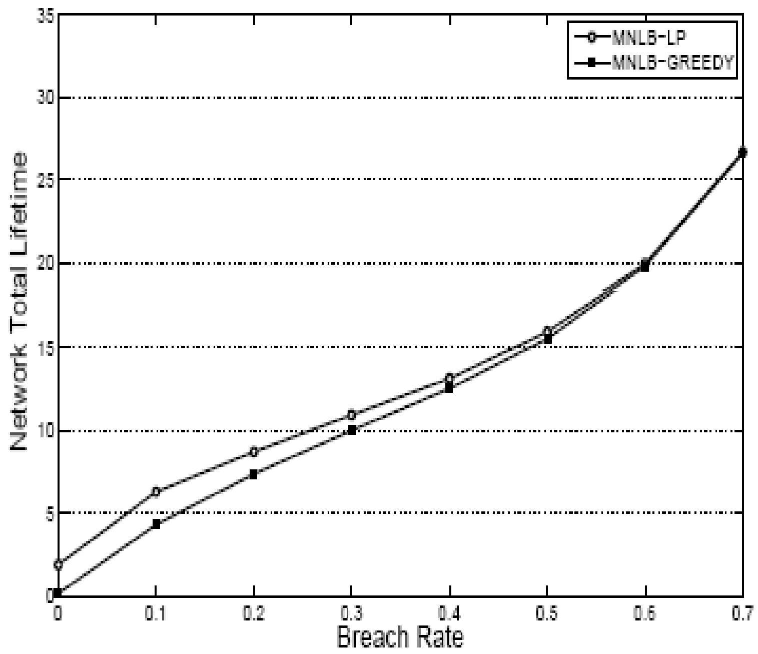
Experimental Performance

- Simulation of MNLB
  - Sensors and targets are uniformly deployed in a 500m by 500m area
  - Default parameters:
    - n = 50
    - m = 30
    - W = 4
    - Sensor range = 150m
    - BR = 0

Experimental Performance (cont'd)



(a) Effect of Bandwidth Constraints



(b) Effect of Breach Rate

Conclusion

- Coverage model with bandwidth constraints are considered: network lifetime and coverage breach.
- A Tradeoff Scheme including MCBB and MNLB are proposed to address the issues.
- A LP-relax algorithm and a greedy heuristic are proposed to solve both problems.
- Simulation results show performances of both of our algorithms as expected.

Q&A

- Thanks!