Differentiated Surveillance for Sensor Networks

Ting Yan, Tian He, John A. Stankovic
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Outline

- Introduction
- Protocol design
- Design issues
- Optimizations and extensions
- Simulation and evaluation
- Conclusion
Introduction

- Wireless sensor networks exploit node density/redundancy to maximize effective network lifetime.
- Degree of coverage
  - Sensing constraints
  - Fault tolerance
Introduction

• In most scenarios such as battlefields, there are certain geographic sections such as command center needing much more security-sensitive than others.

• It is overkill and energy consuming to support the same high degree of coverage for some non-critical area.

• The goal of the paper is to propose a protocol to dynamically decide the schedules for nodes to guarantee a certain degree of coverage (maybe <= 100%)
Assumptions

• Static placement
• Known location
• Time Synchronization (millisecond level)
• For simplicity of describing protocol?
  - Nodes on 2D plane
  - Circular sensing radius $r$
  - Communication range $> 2r$
Basic Protocol without differentiation

- Initialization Phase
  - Localization, Time Sync, Determine Working Schedule \((T, \text{Ref}, T_{\text{front}}, T_{\text{end}})\)
    - \(T\): the duration of each round
    - \(\text{Ref}\): a random time reference point chosen by a node within \([0, T)\)
    - \(T_{\text{front}}\): The duration of time prior to the reference point \(\text{Ref}\)
    - \(T_{\text{end}}\): The duration of time after to the reference point \(\text{Ref}\)
Basic Protocol without differentiation

- Sensing Phase
  - Nodes power on and off based on working schedule
Basic Protocol

Determining Working Schedule

• Goal: Each node determines its own working schedule such that all grid points within sensor coverage are covered for all time.

• Approach: Represent sensor coverage with grid of points.
Basic Protocol
Determining Working Schedule

- **Reference Point Scheduling Algorithm**
  - Randomly choose $Ref$ from $[0, T)$ and broadcast to all nodes within $2r$.
  - For each grid point
    - Order neighboring $Ref$ times and calculate
      - $T_{\text{front}} = \frac{[Ref(i)-Ref(i-1)]}{2}$
      - $T_{\text{end}} = \frac{[Ref(i+1)-Ref(i)]}{2}$
  - Final schedule = union of schedules for all points
Basic Protocol

Determining Working Schedule

• Ex. T = 30 minutes and nodes A, B, C can cover the grid point “x”.
  - A, B, C choose Ref values 4,12,22.
  - Node B would set $T_{\text{front}} = (12 - 4)/2 = 4$
    $T_{\text{end}} = (22 - 12)/2 = 5$
  - Node A $(T, \text{Ref}, T_{\text{front}}, T_{\text{end}}) = (30, 4, 6, 4)$
  - Node B $(T, \text{Ref}, T_{\text{front}}, T_{\text{end}}) = (30, 12, 4, 5)$
  - Node C $(T, \text{Ref}, T_{\text{front}}, T_{\text{end}}) = (30, 22, 5, 6)$
Schedule for Node B

Schedule for Node C

Schedule for Node A
union of schedules for all points

Round Begins

for grid point a

T_{front} \quad T_{end}

for grid point b

T_{front} \quad T_{end}

\ldots

for grid point y

T_{front} \quad T_{end}

for grid point z

T_{front} \quad T_{end}

Integrated Schedule

T_{front} \quad T_{end}
Enhanced Protocol with Differentiation

• Working schedule for a desired coverage of degree $\alpha$.
  - $(T, \text{Ref}, T_{\text{front}}, T_{\text{end}}, \alpha)$
  - Working period defined as:
    • Power On: $T \times i + \text{Ref} - T_{\text{front}} \times \alpha$
    • Power Off: $T \times i + \text{Ref} + T_{\text{end}} \times \alpha$

Example ($\alpha = 1$)

Example ($\alpha = 2$)

Example ($\alpha = 3$)

Uh-Oh!
Design Issues

• Possible blind points due to large granularity of the grid size
  – use conservative sensing range smaller than actual range

• Possible blind points due to synchronization skew
  – Increase the time duration T for each round

• Irregular sensing regions
  – Okay, as long as sensing regions of neighboring nodes are known
  – But also requires to exchange knowledge of sensing regions

• Fault Tolerance
  – Awake nodes use heartbeat messages to detect failed nodes
  – If a node fails, wakeup all nodes within 2r and reschedule.
Extensions and Optimizations

• Second Pass Optimization
  – After determining working schedule, broadcast schedule to all nodes within $2r$.
  – The node which has the longest schedule:
    • Minimize $T_{front}$ and $T_{end}$ while maintaining sensing guarantee based on other schedules.
    • Rebroadcasts new schedule
  – Done when every node has recalculated schedule or when no more can be done.
Extensions and Optimizations

• Energy consumption variance in the protocol can be attributed to at least two reasons.
  - The randomness of node deployment, some nodes may have fewer neighbors in the range of 2r and little can be done to the problem.
  - The randomness the reference time. If the selected reference times are very close to each other, there must be an extraordinarily long schedule.
Extensions and Optimizations

• Multi-Round Extension for Energy Balance
  - Calculate $M$ schedules each with different Ref values during Init Phase.
  - Rotate schedules during Sensing Phase.

\[ \text{Schedule 1} \quad \text{Schedule 2} \quad \text{Schedule 3} \quad \text{Schedule 4} \]
Evaluation

• Simulation parameters
  - Nodes distributed randomly with uniform distribution in 160mX160m field.
  - Results taken from center 140mX140m to avoid edge effects
  - Sensing range = 10m
  - Communication range = 25m
  - Ideal conditions

• Compare against sponsored approach
Evaluation

- Total energy consumption nearly constant with changes in density.
- Variation in total energy consumed decreases with greater densities.
- What’s happening with the sponsored approach?
Evaluation

- Half-life increases linearly as density increases.

- Coverage provided for longer period of time.
Evaluation

- Energy consumption increases linearly with different degrees.
- Energy consumption constant with different densities.
- Degree of coverage provided $\geq a$.
- $a$ only guarantees a lower bound.
Conclusion

• **Pros**
  - Propose a differentiated surveillance protocol
  - Improved performance in lifetime and workload balance
  - Specify a degree of coverage

• **Cons**
  - Inflexible
    • Static working schedule, static nodes, time synchronization, reliable communication