Differentiated Surveillance for Sensor Networks

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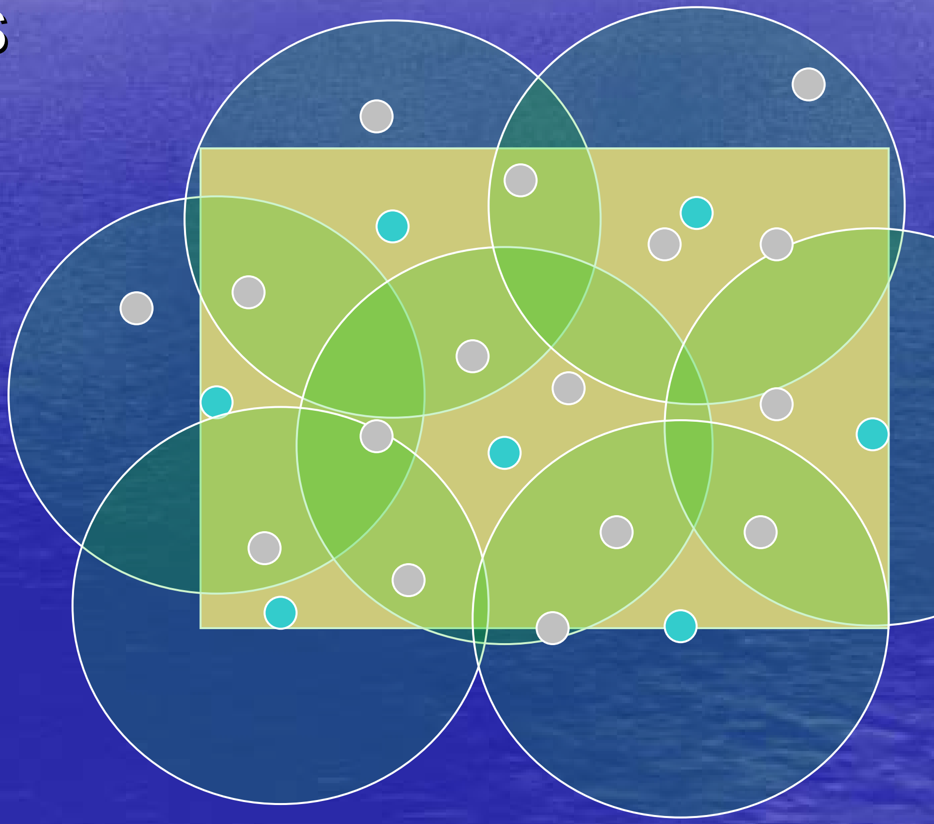
Outline

- 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

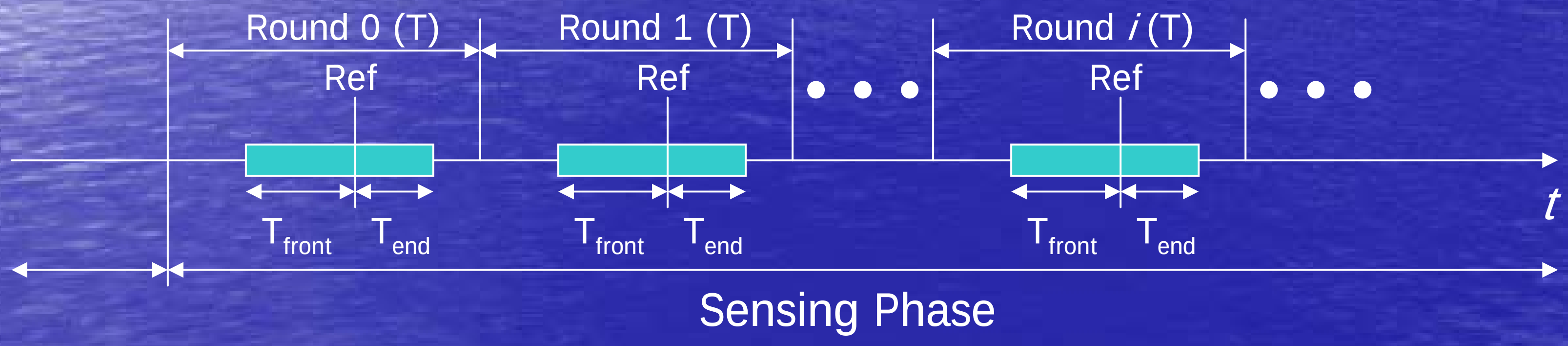
- Static placement
- Known location
- Time Synchronization(millisecond level)
- For simplicity of describing protocol?
  - Nodes on 2D plane
  - Circular sensing radius *r*
  - Communication range > 2*r*

Basic Protocol without differentiation

- Initialization Phase
  - Localization, Time Sync, Determine Working Schedule (T, Ref, T_{front}, T_{end})
    - T : the duration of each round
    - *Ref* : a random time reference point chosen by a node within [0, T)
    - T_{front} : The duration of time prior to the reference point *Ref*
    - T_{end} : The duration of time after to the reference point *Ref*

Basic Protocol without differentiation

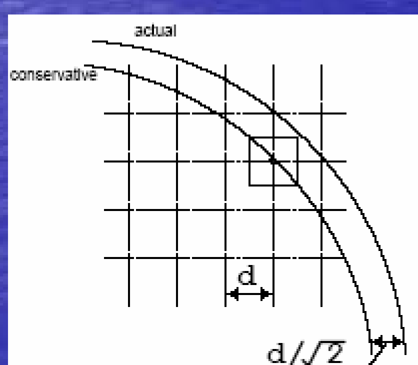
- Sensing Phase
  - Nodes power on and off based on working schedule

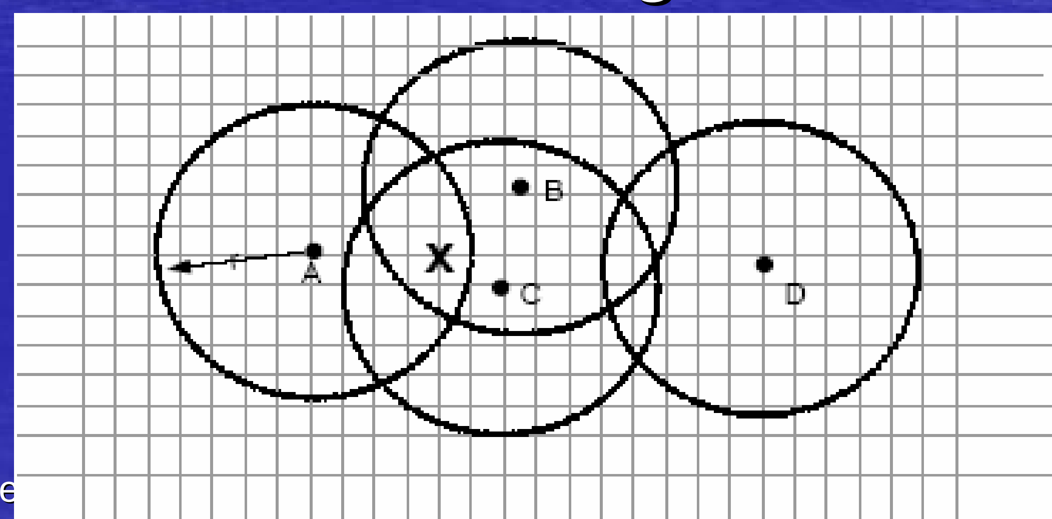


Basic Protocol

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



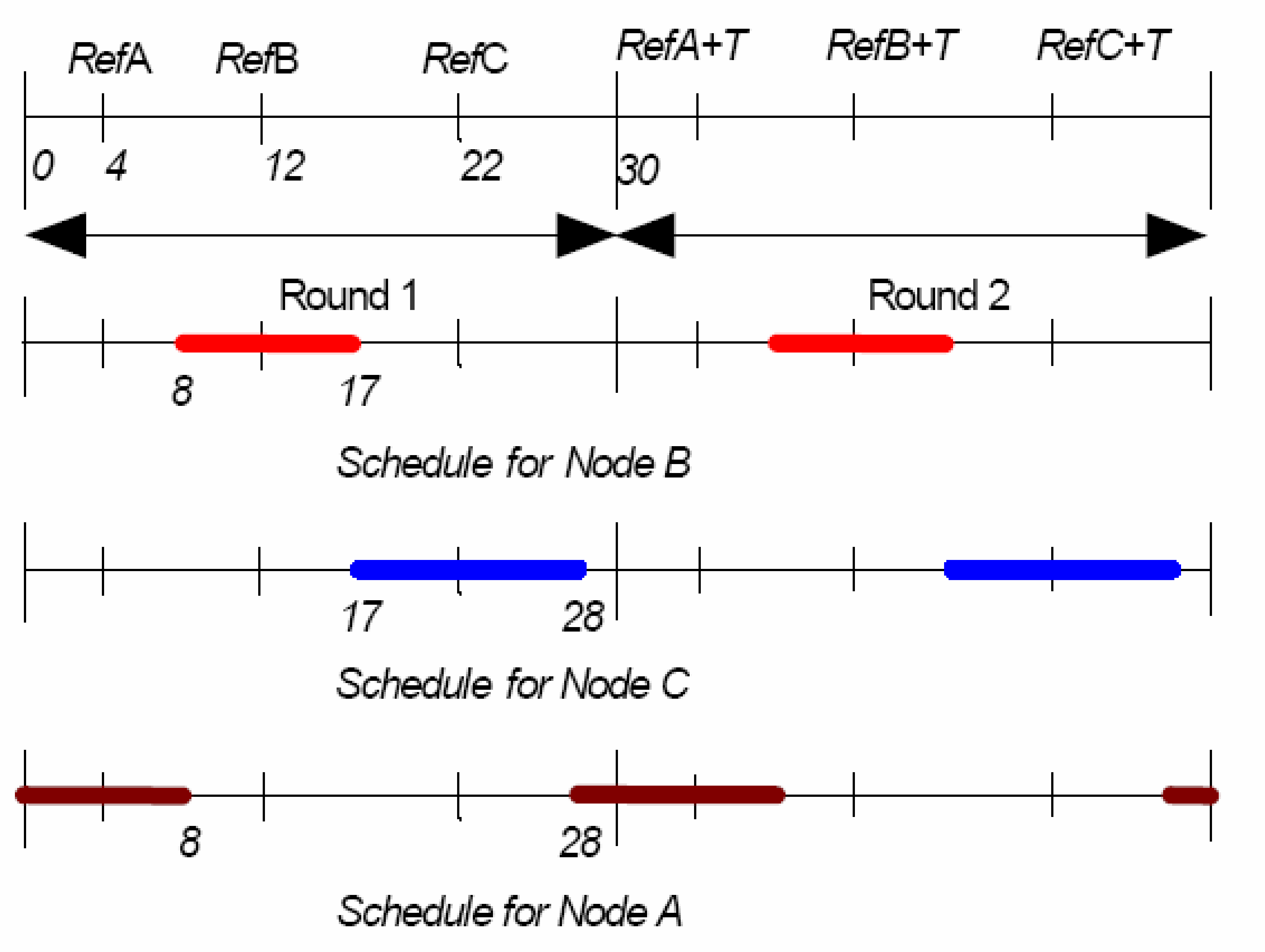


Basic Protocol
Determining Working Schedule

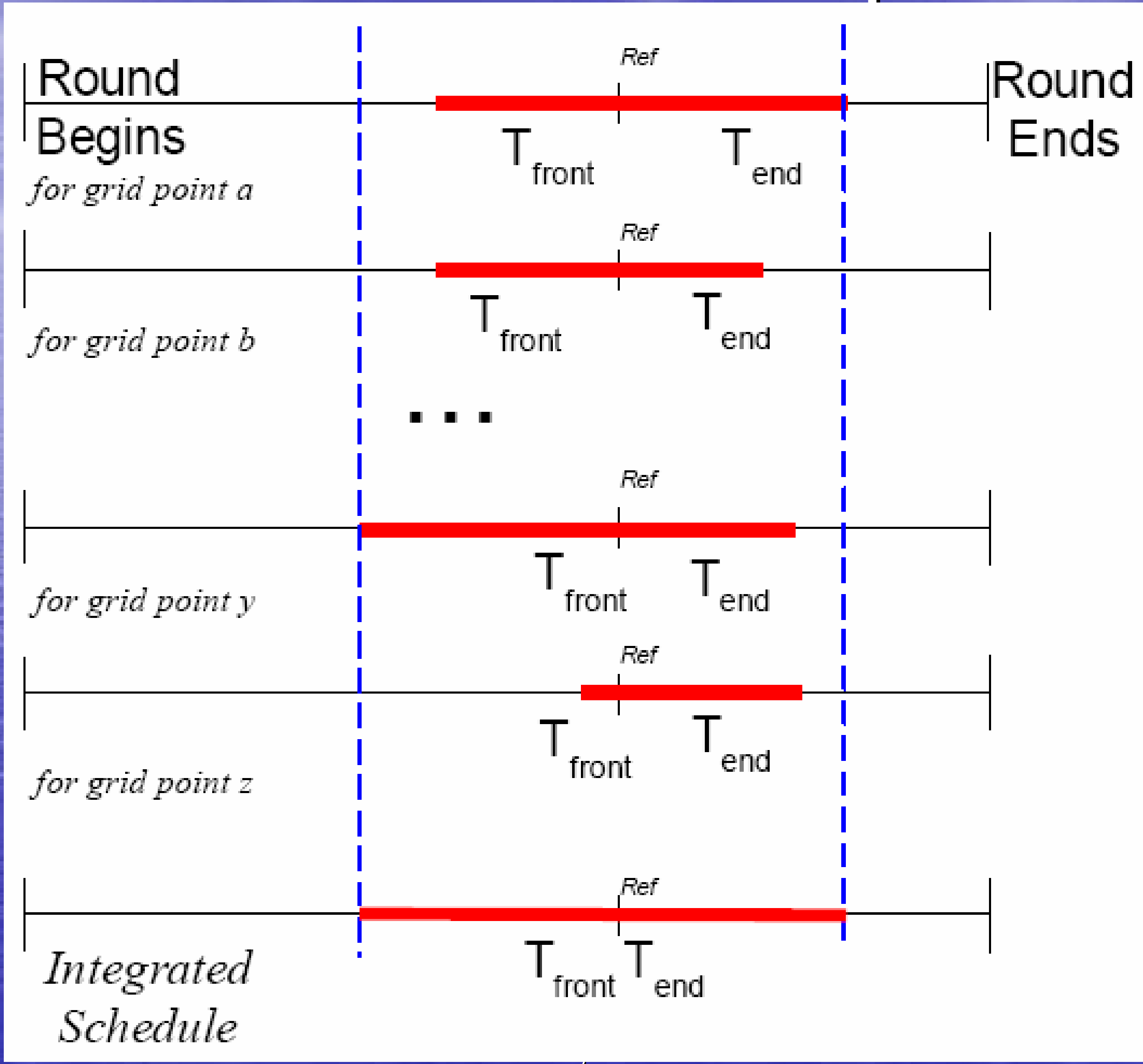
- Reference Point Scheduling Algorithm
  - Randomly choose *Ref* from [0, T) and broadcast to all nodes within 2*r*.
  - For each grid point
    - Order neighboring *Ref* times and calculate
      - T_{front} = [$Ref(i)$-$Ref(i-1)$]/2
      - T_{end} = [$Ref(i+1)$-$Ref(i)$]/2
  - Final schedule = union 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_{front} = (12- 4)/2=4
    T_{end} = (22-12)/2=5
  - Node A $(T, Ref, T_{front}, T_{end}) = (30, 4, 6, 4)$
    Node B $(T, Ref, T_{front}, T_{end}) = (30, 12, 4, 5)$
    Node C $(T, Ref, T_{front}, T_{end}) = (30, 22, 5, 6)$


RefA
RefB
RefC
RefA+T
RefB+T
RefC+T
0
4
12
22
30
Round 1
Round 2
8
17
Schedule for Node B
17
28
Schedule for Node C
8
28
Schedule for Node A

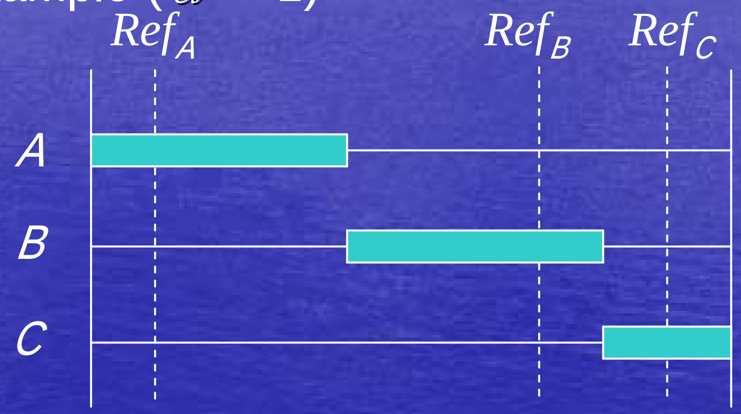
union of schedules for all points



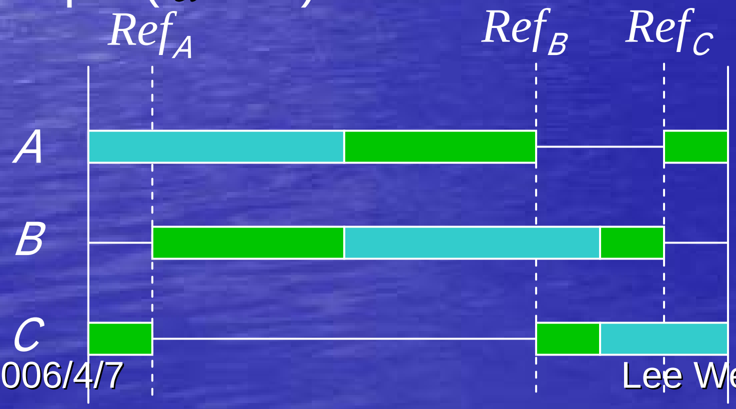
Enhanced Protocol
with Differentiation

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

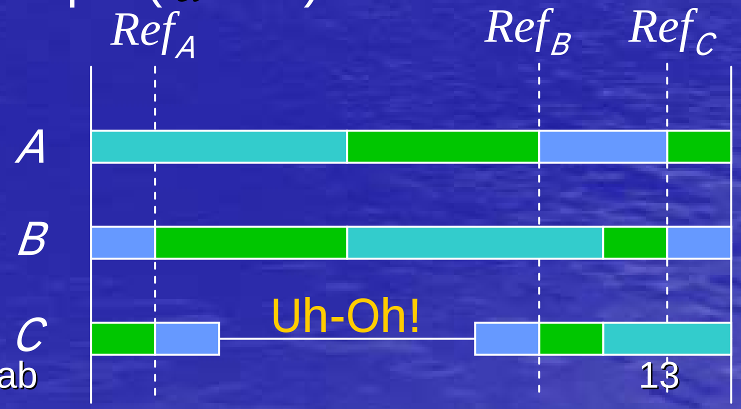
Example (α = 1)



Example (α = 2)



Example (α = 3)



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

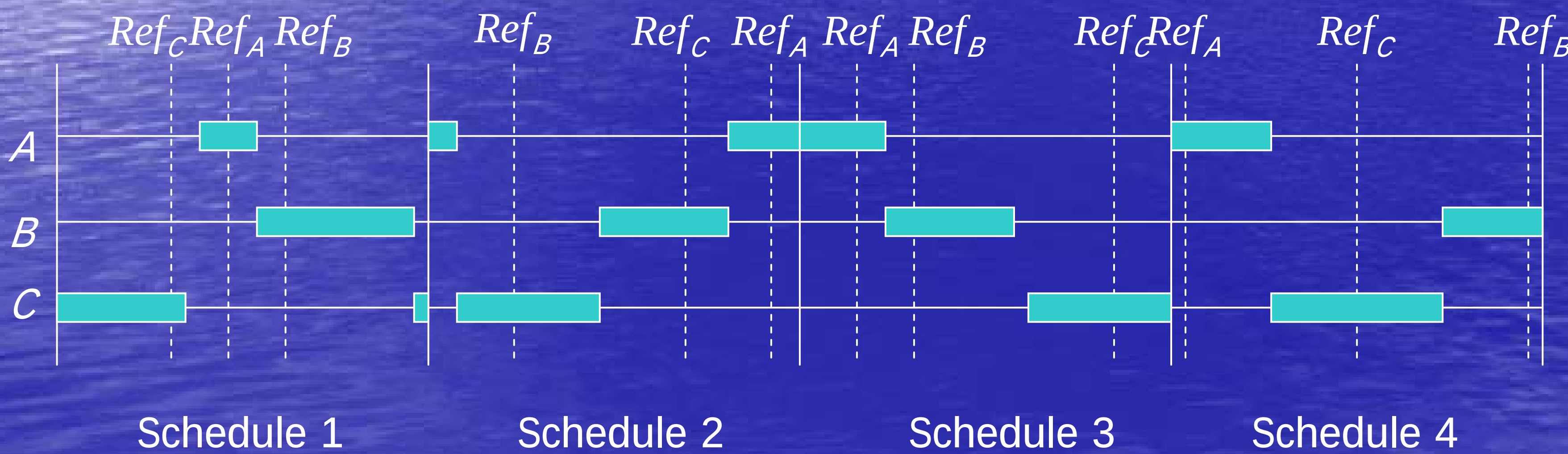
- Second Pass Optimization
  - After determining working schedule, broadcast schedule to all nodes within 2*r*.
  - The node which has the longest schedule:
    - Minimize T_{front} and T_{end} while maintaining sensing guarantee based on other schedules.
    - Rebroadcasts new schedule
  - Done when 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

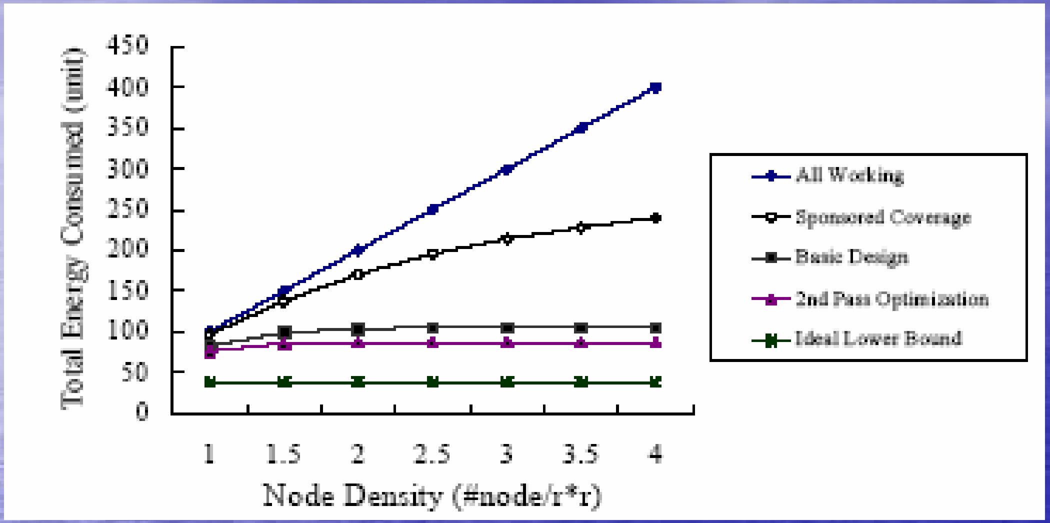
- Multi-Round Extension for Energy Balance
  - Calculate *M* schedules each with different *Ref* values during Init Phase.
  - Rotate schedules during Sensing Phase.

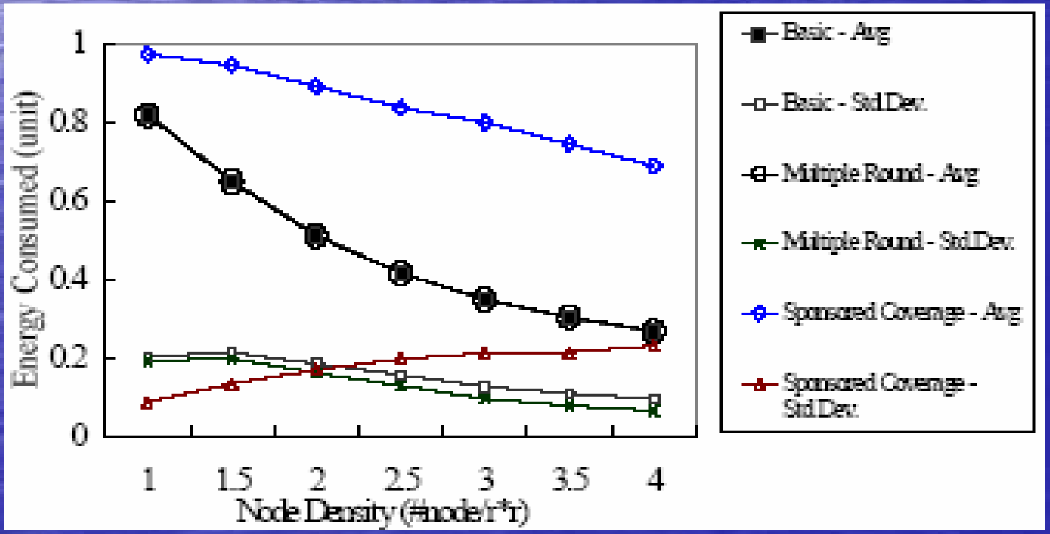


Evaluation

- 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

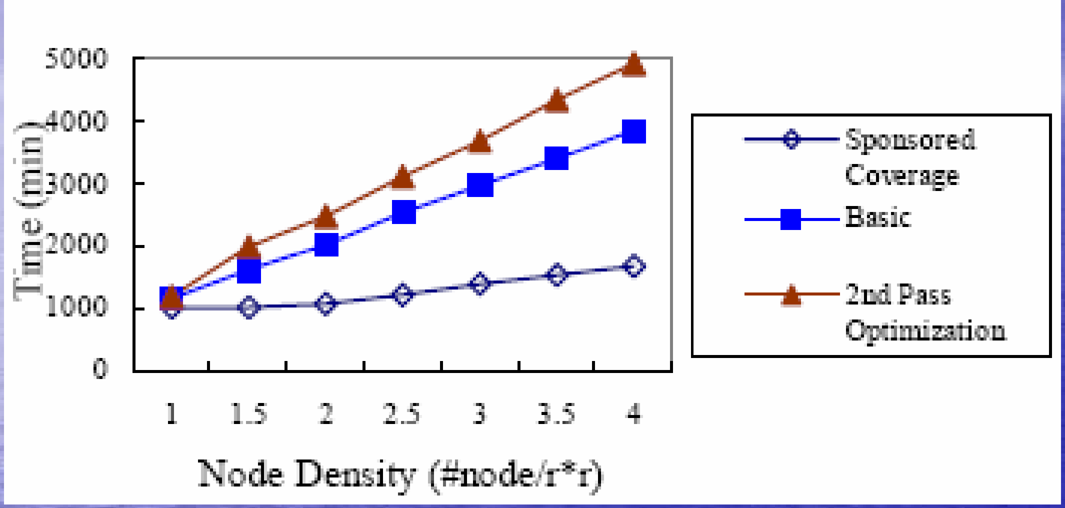
Evaluation

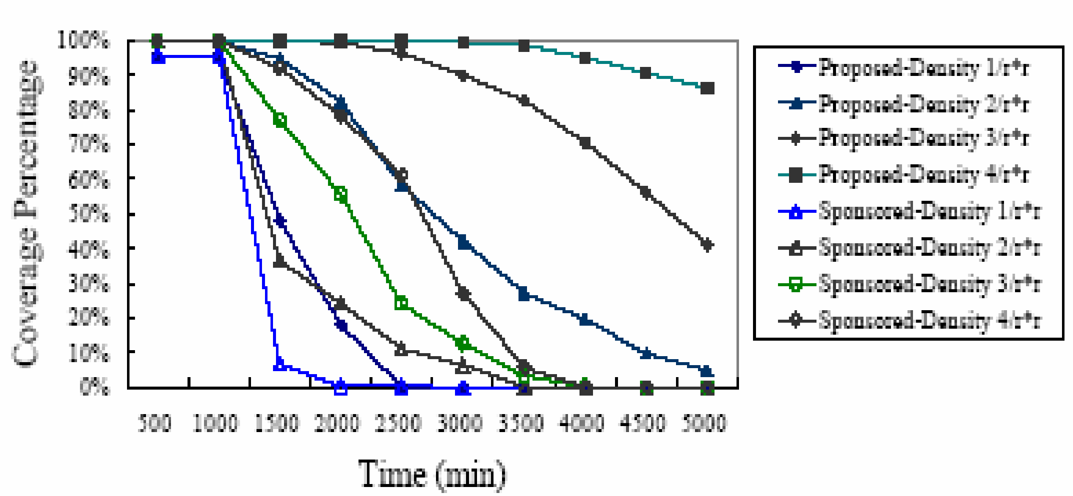




- Total energy consumption nearly constant with changes in density.
- Variation in total energy consumed decreases with greater densities.
- What's happening with the sponsored approach?

Evaluation

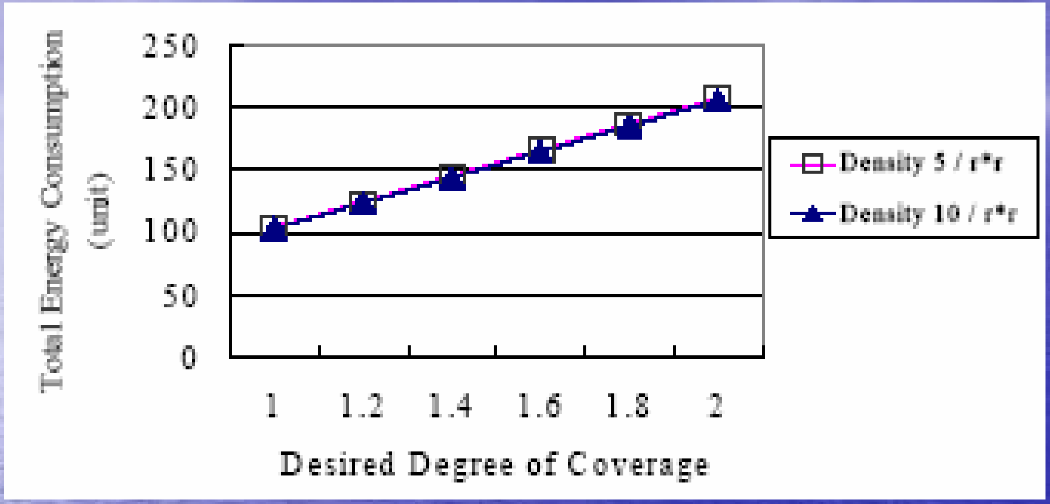


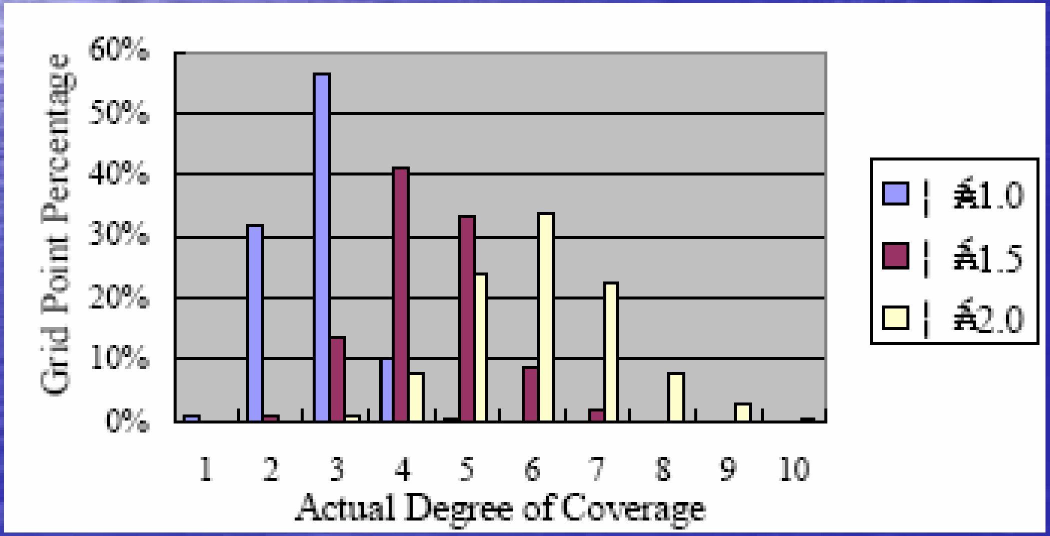


- Half-life increases linearly as density increases.

- 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 >= *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