Power Conservation and Quality of Surveillance in Target Tracking Sensor Networks

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Surveillance Sensor Networks

- Surveillance Sensor Network Application
  - Structure defect detection
  - Battle field surveillance
  - Forest fire detection
- A special case: Target Tracking Applications
  - After detection of a moving object, need to track the object's location in real-time

Target tracking with Sensor Network

- General problem statement
  - A varying number of targets
    - Arise at random in space and time
    - Move with continuous motions
    - Persist for a random length of time and disappear
  - Goal: For each target, find its track

Power Conservation in Surveillance Sensor Network

- Need to operate unattended, as long as possible
- Events occurrence
  - random sporadic,
  - long intervals of null state
- Sleeps during the null interval: save more power
- Two states for a sensor node:
  - Surveillance state

    no events of interest in the field, but ready to detect any possible occurrences
  - Tracking state

    reacts in response to any moving target, sensors collaborate in tracking

Scope of This Work

- Study the trade-off between power conservation and surveillance
  - Define new metrics for Quality of Surveillance (QoSv)
- Analyze the various sleeping methods
- Novel transition scheme between two states

Quality of Surveillance (QoSv)

- Coverage-based QoSv metrics
  - P-coverage
  - α-coverage
- Not suitable for QoSv on mobile objects
  - Full coverage is not necessary for moving object
  - Coverage metrics do not measure QoSv directly

QoSv metrics: Ideal metric

- What is the distance traveled by the target remaining uncovered before it intersects with the sensing boundary of a sensor node?

- Ideal metric:

$$QoSv(X) \equiv \frac{1}{L^*}$$

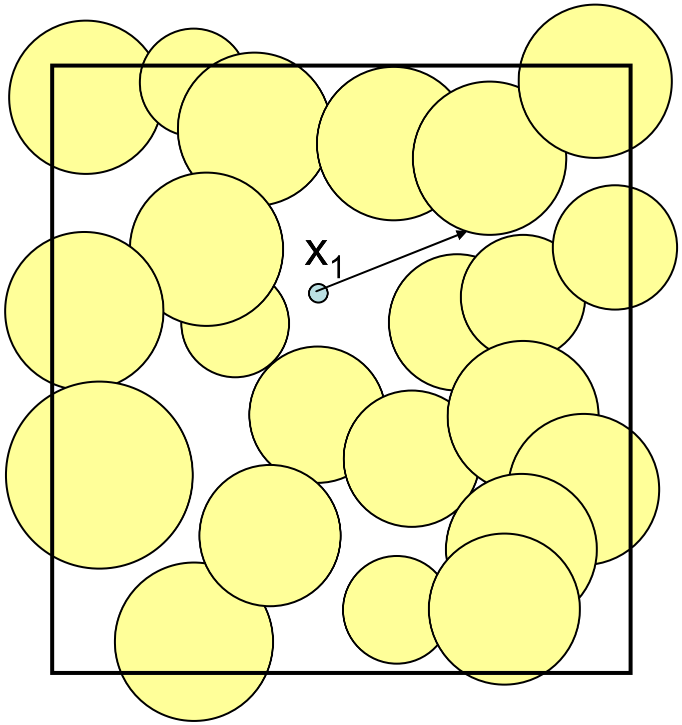
  - $\mathcal{L}$ is the traveled distance in the previous question, $\mathcal{L}^*$ is expected value of $\mathcal{L}$
  - $\mathcal{X}$ denotes the field of SN deployment

QoSv metrics: Workable metric

- Workable QoSv metric: ALUL(X)
  - Average Linear Uncovered Length (ALUL)
  - Assumption
    - Targets move continuously
    - Targets can only move for a short distance before being detected
  - A line segment can approximate the uncovered moving path

Workable QoSv metric: ALUL

- Definitions
  - Linear Uncovered Length (LUL) at position x on direction θ – LUL(x, θ).



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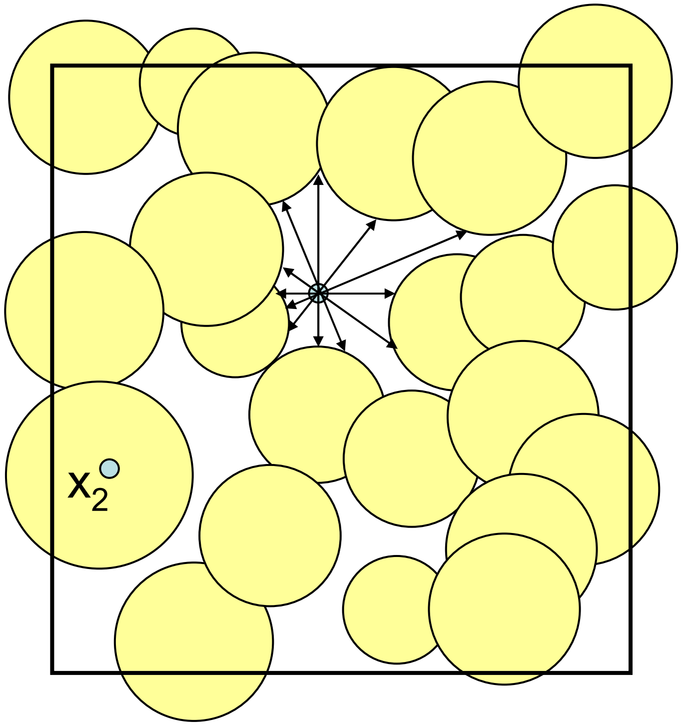
  - Average Uncovered Length (ALUL) at position x – ALUL(x).
    - $ALUL(x_2) = 0$



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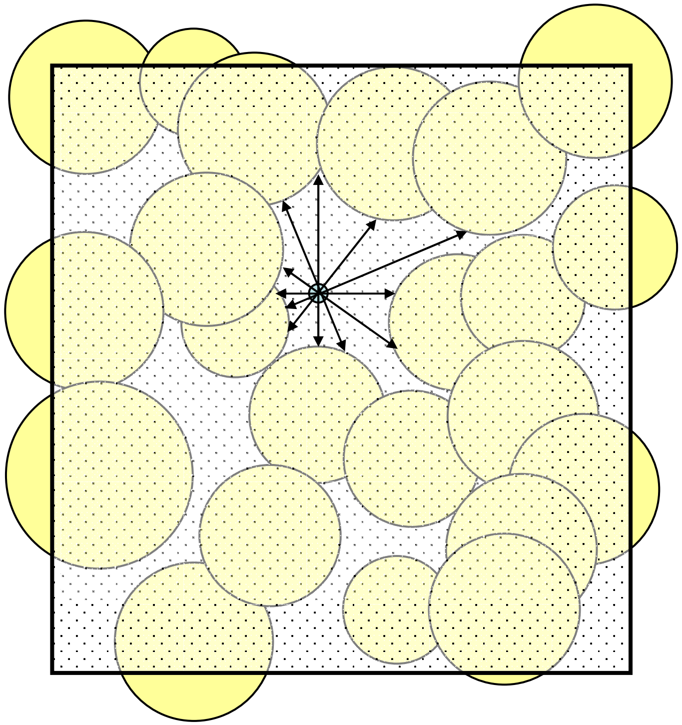
    - $ALUL(x_2) = 0$
  - Average Uncovered Length (ALUL) for field X – ALUL(X)



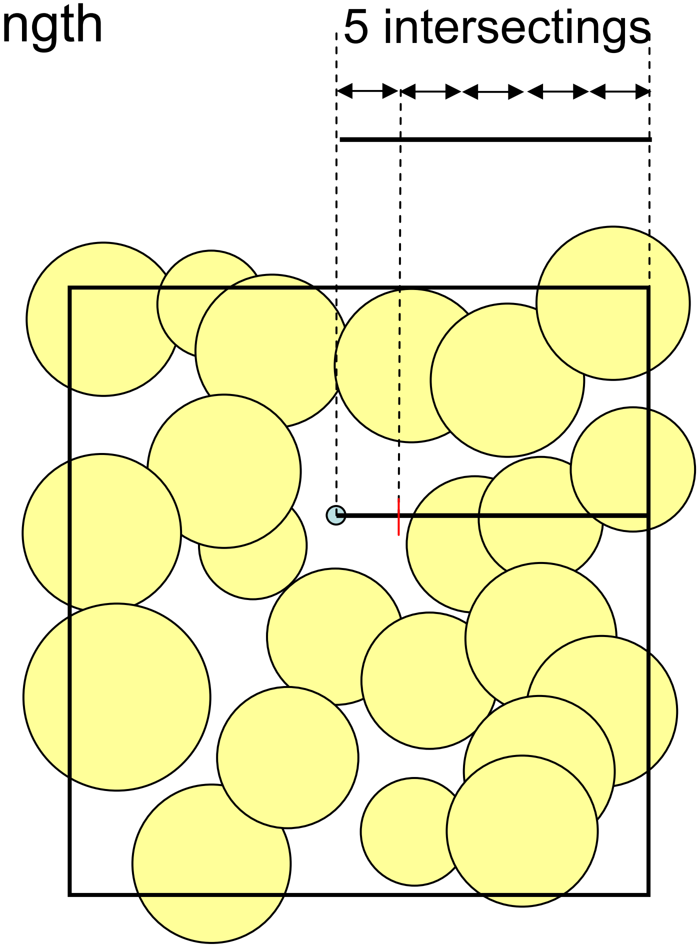
Approximation of ALUL(X)

- **Theorem:** For any straight line of length l in the field, the expected number of intersections the line with the disc boundaries is

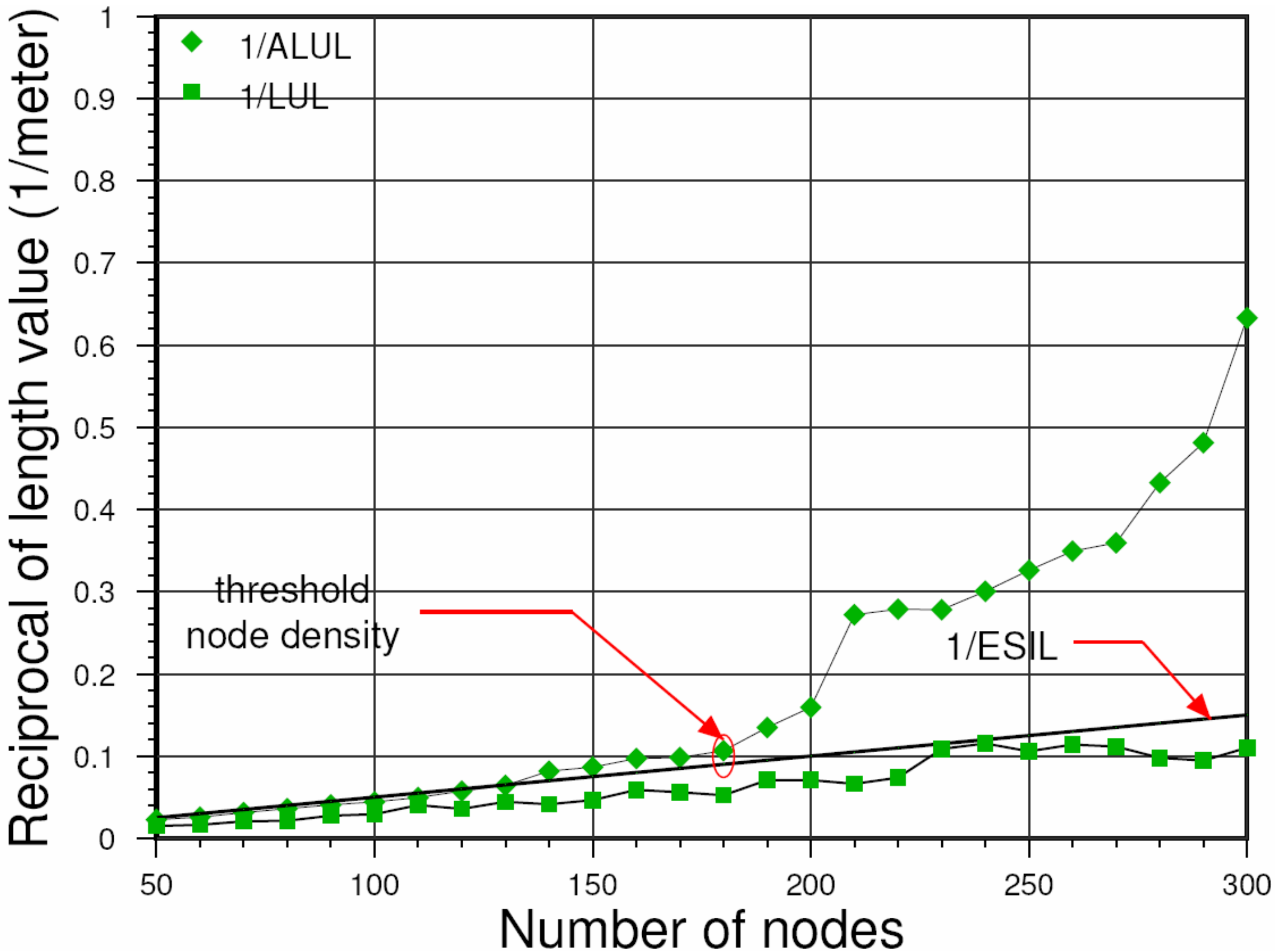
$$e = \frac{4n \cdot \bar{r} \cdot l}{\|X\|}$$

- Proposition: For any straight line of length l, *and let* e *be expected number of intersections within disc boundaries,* l/e *approximates* ALUL(X).
- Conclusion:

$$QoSv(X) \equiv \frac{1}{ALUL(X)} \cong \frac{4n \cdot \bar{r}}{\|X\|}$$



Experimental Result



Role QoSv Study

- QoSv study guides sensor deployment
  - Number of nodes
  - Distribution

Role of Sleep Planning

- Make spare nodes sleep
  - Over-deployment of sensor nodes
- Active nodes follow deployment guideline

Sleep Planning Methods

- Random Independent Sleeping (RIS)
  - Independent decide when to wake-up
  - Randomized schedule
- Neighbor Collaborative Sleeping (NCS)
  - Collaborate on whose turn to be on duty
- Planned Distribution Methods
  - Use location info., make the active nodes distribute in a planned manner

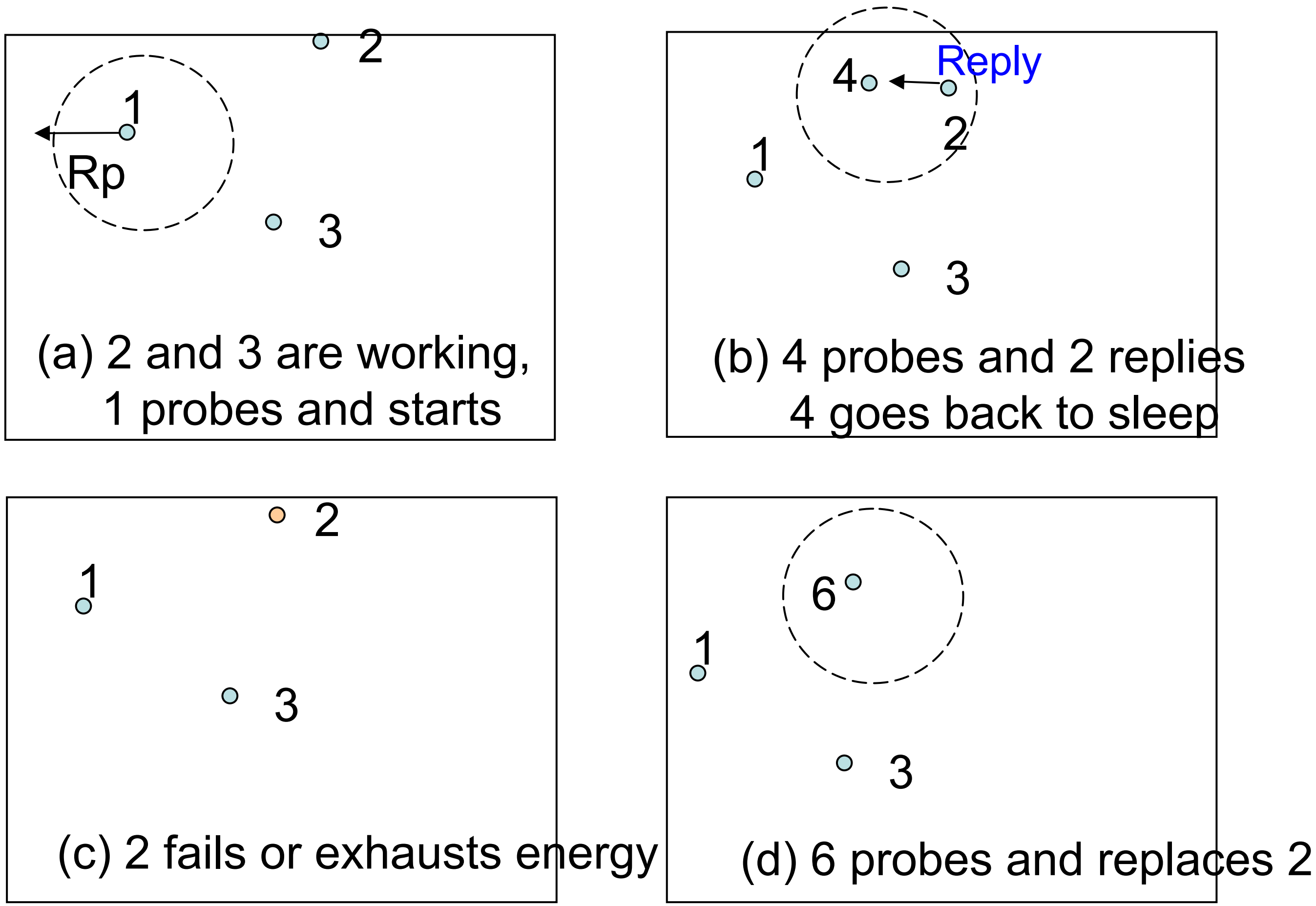
Random Independent Sleeping

- Alertness level $$a = \frac{n^*}{N}$$

- Each node remain active for *a* percent of total time.
  - Timeslots
  - Within each timeslot, active for $a*T_{slot}$
  - Randomized timeslot boundaries

Neighbor Collaborative Sleeping

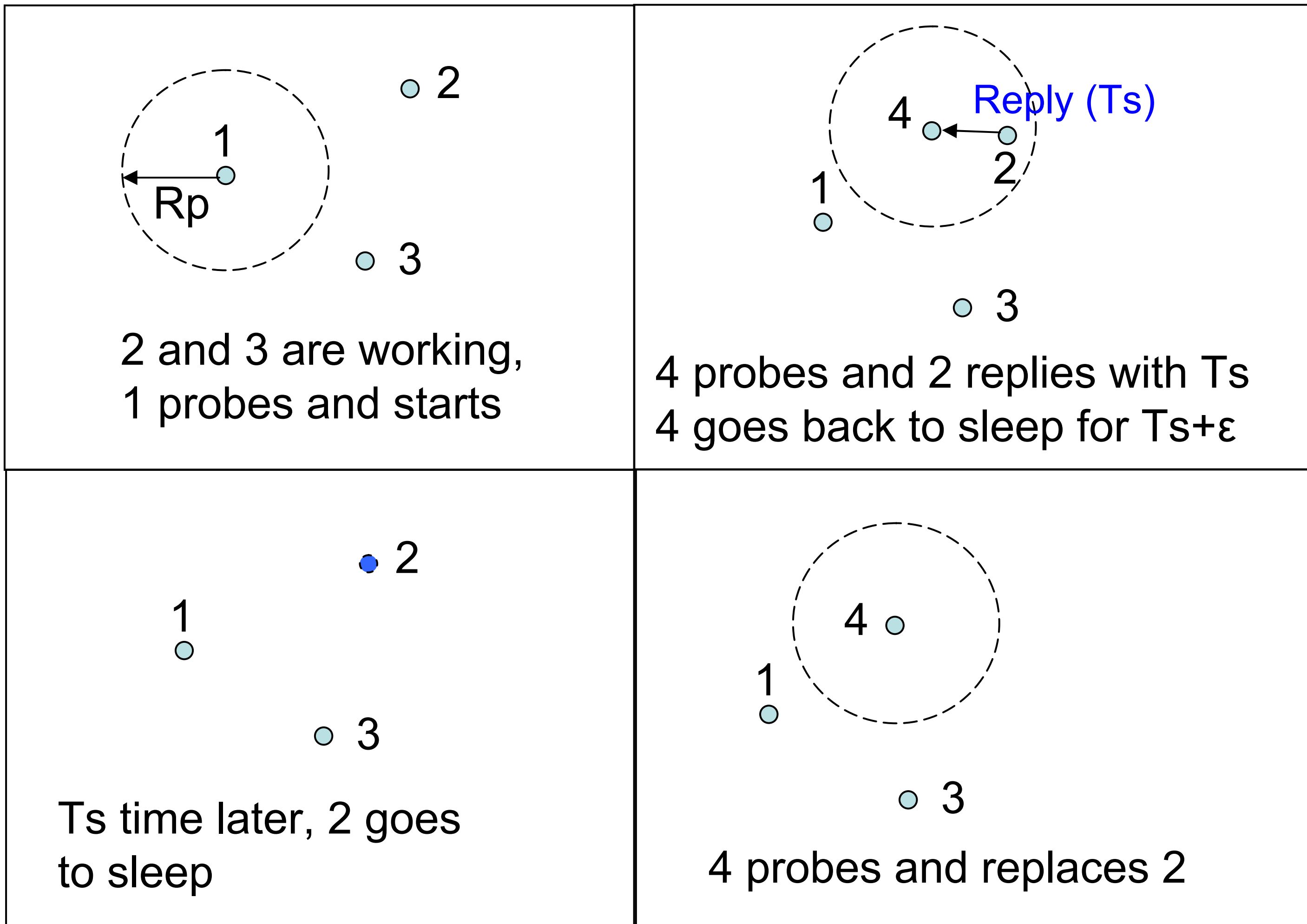
- PEAS (Ye-2003), GAF(Xu-2001)



Revised PEAS

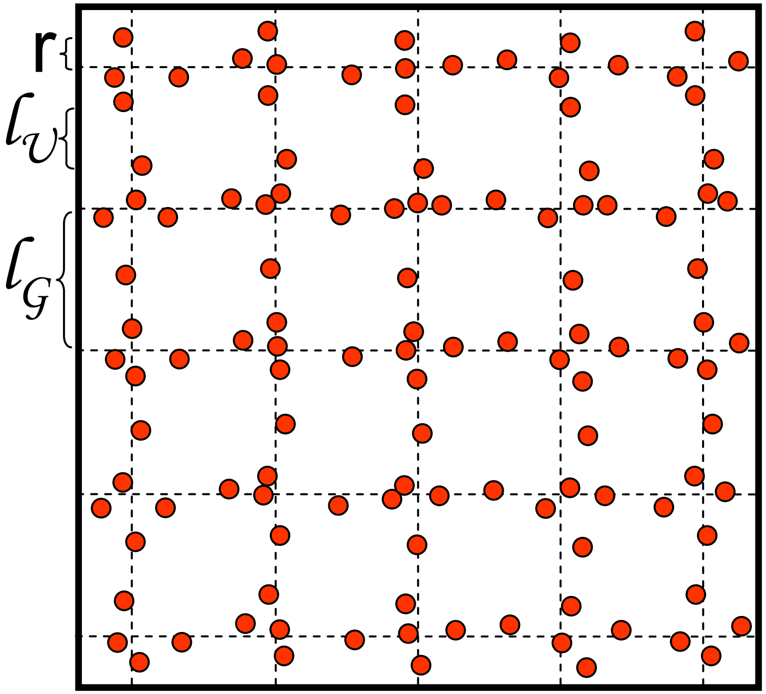
- Why revise
  - Once starts working, a node does not sleep
  - Goal: Nodes take turn for duty, balance energy consumption among all nodes
- PECAS – Probe Environment and Collaborated Adaptive Sleeping

PECAS by example



Planned Distribution Methods: 2-D Mesh

- Only nodes at planned locations are active
- Use 2-D mesh for spatial pattern
- Parameters:
  - r: Sensing range,
  - l_G:Grid spacing,



Deterministic ALUL(X)

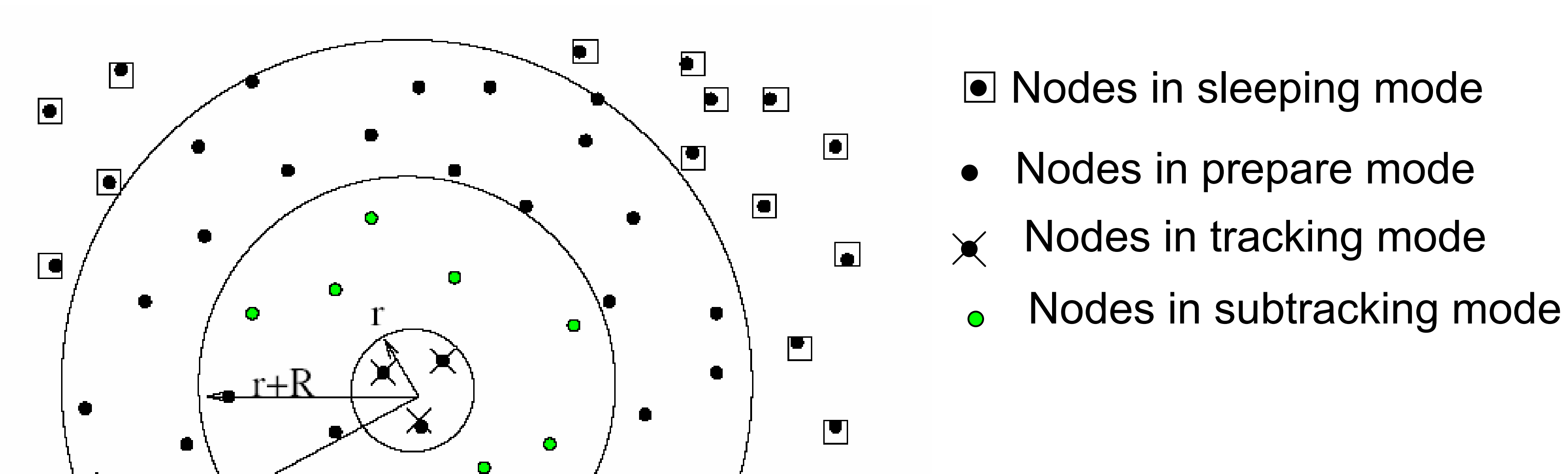
- Theorem: Let X be the monitored area of size L*L. The physical deployment of sensors is uniformly random distribution of adequate density. The distribution of active sensors follows the 2-D mesh planned pattern. Then, ALUL(X) is:

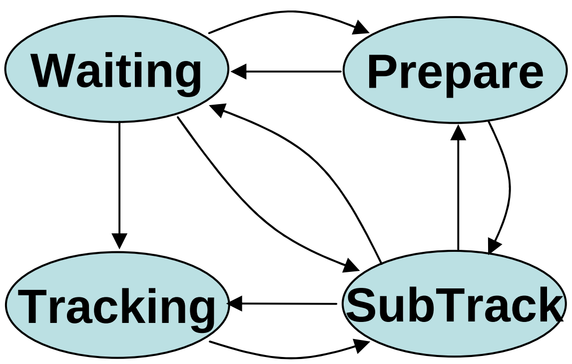
$$ALUL(X) = \frac{2}{\pi}\left(\left\lfloor \frac{L}{l_G} \right\rfloor\right)^2 \frac{(l_G - 2r - 2\delta)^3}{L^2}$$

Proactive Wake-up

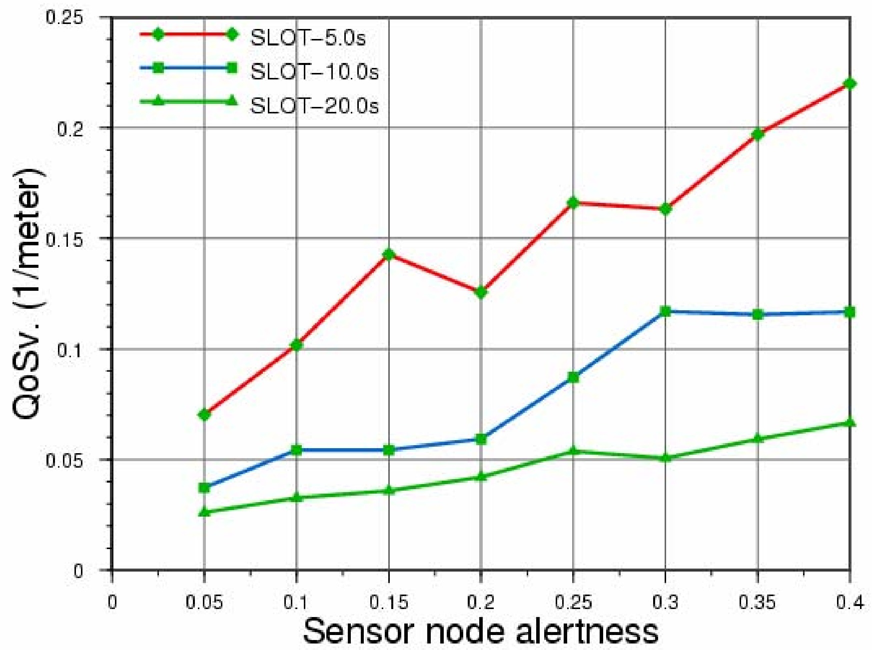
- Two working states a each sensor node
  - Surveillance state (power saving state)
  - Tracking state
- Role of Proactive Wake-up
  - Change from power saving state to tracking state when target comes near
  - Change back to power saving state when target goes away

Layered node state distribution around the target

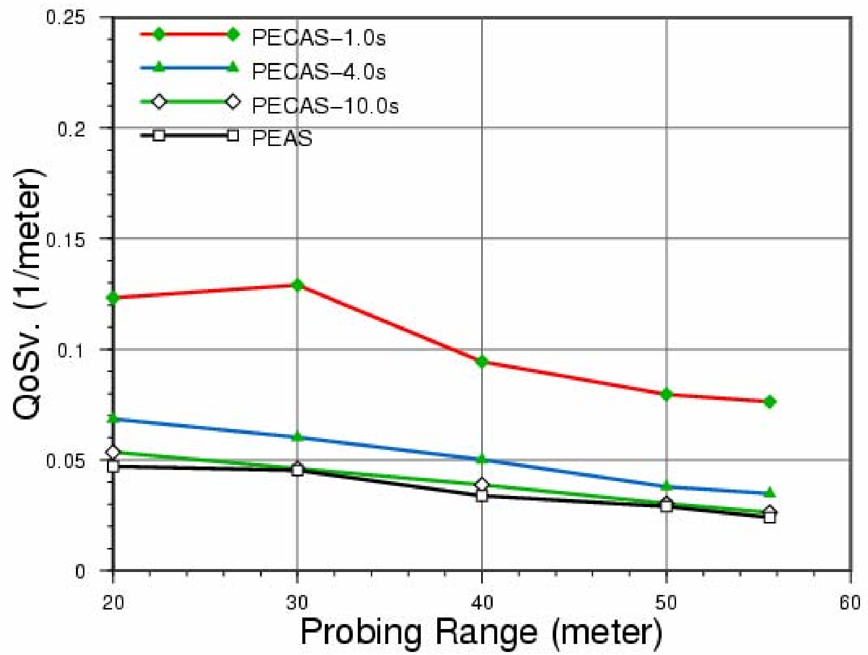




Performance Evaluation: QoSv

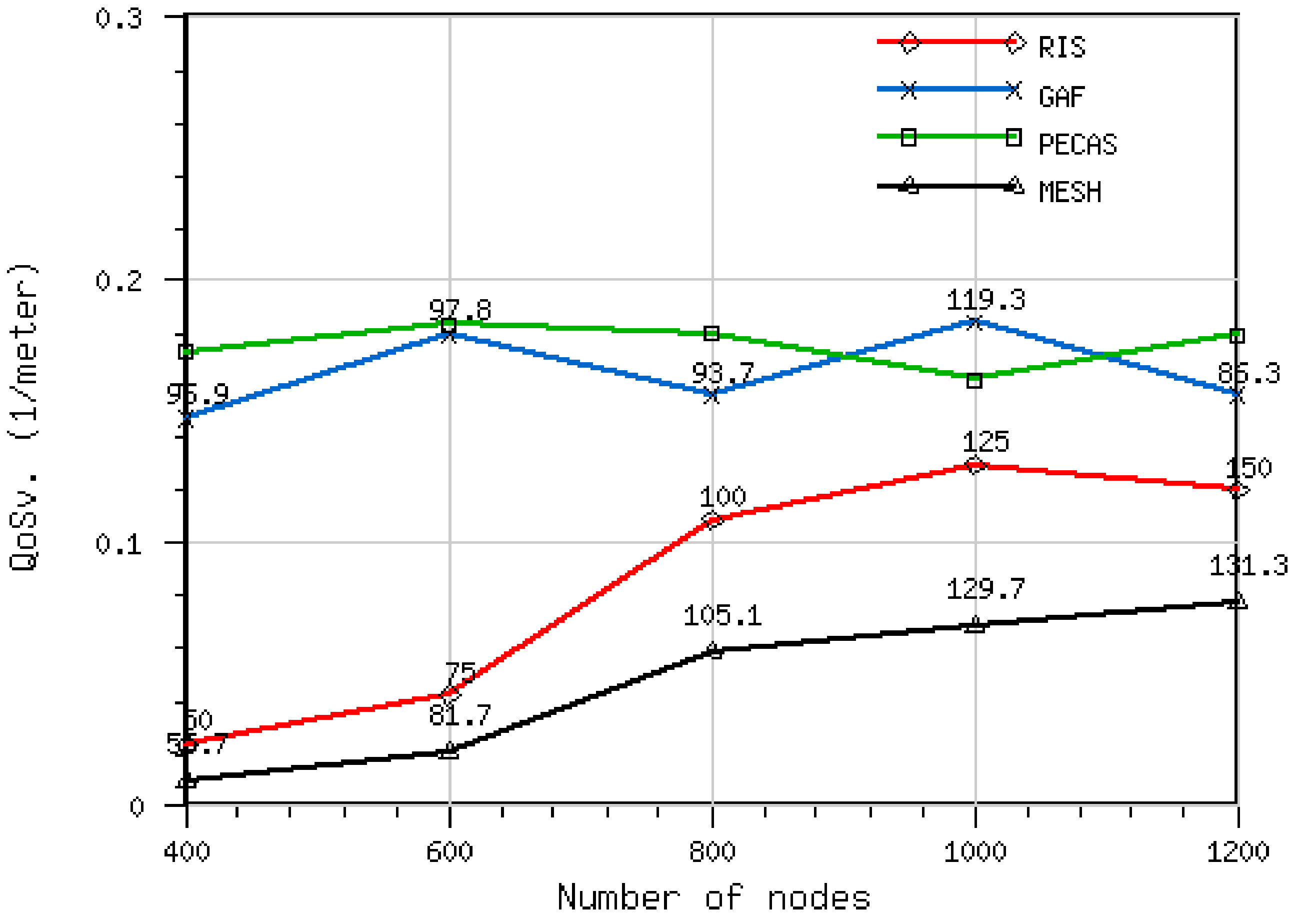


(a) QoSv using RIS.

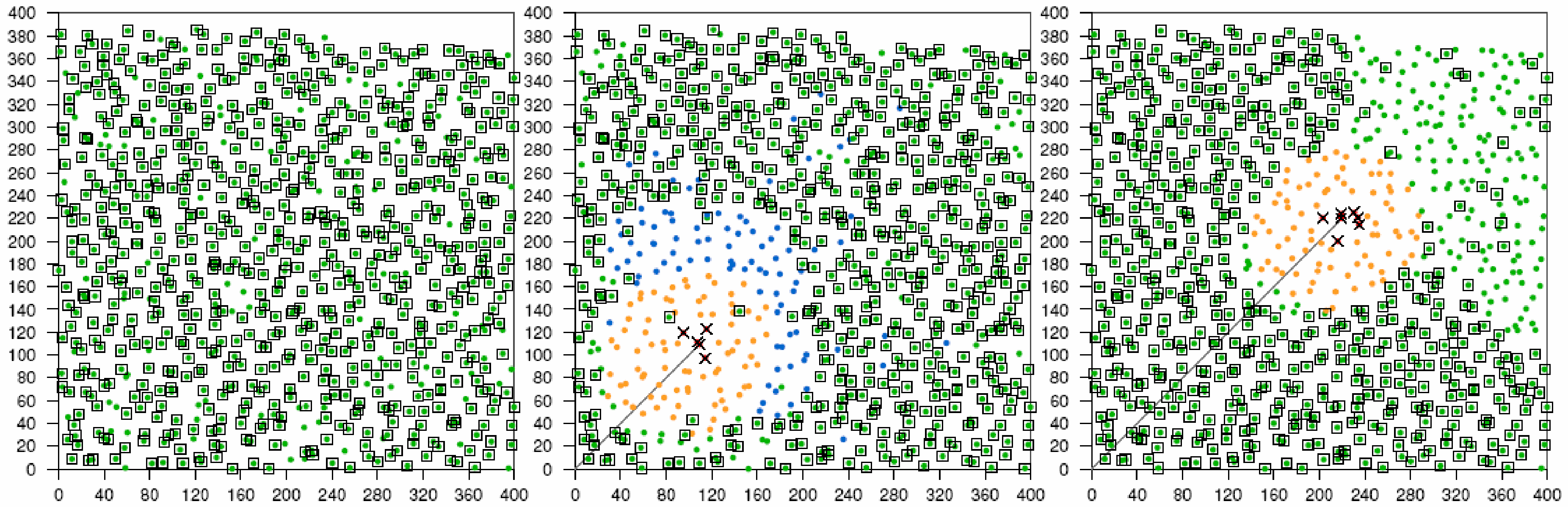


(b) QoSv using PEAS and PECAS.

QoSv Comparison



Performance Evaluation



(a) Timestamp=0.0 second (b) Timestamp=15.0 second (c) Timestamp=31.0 second

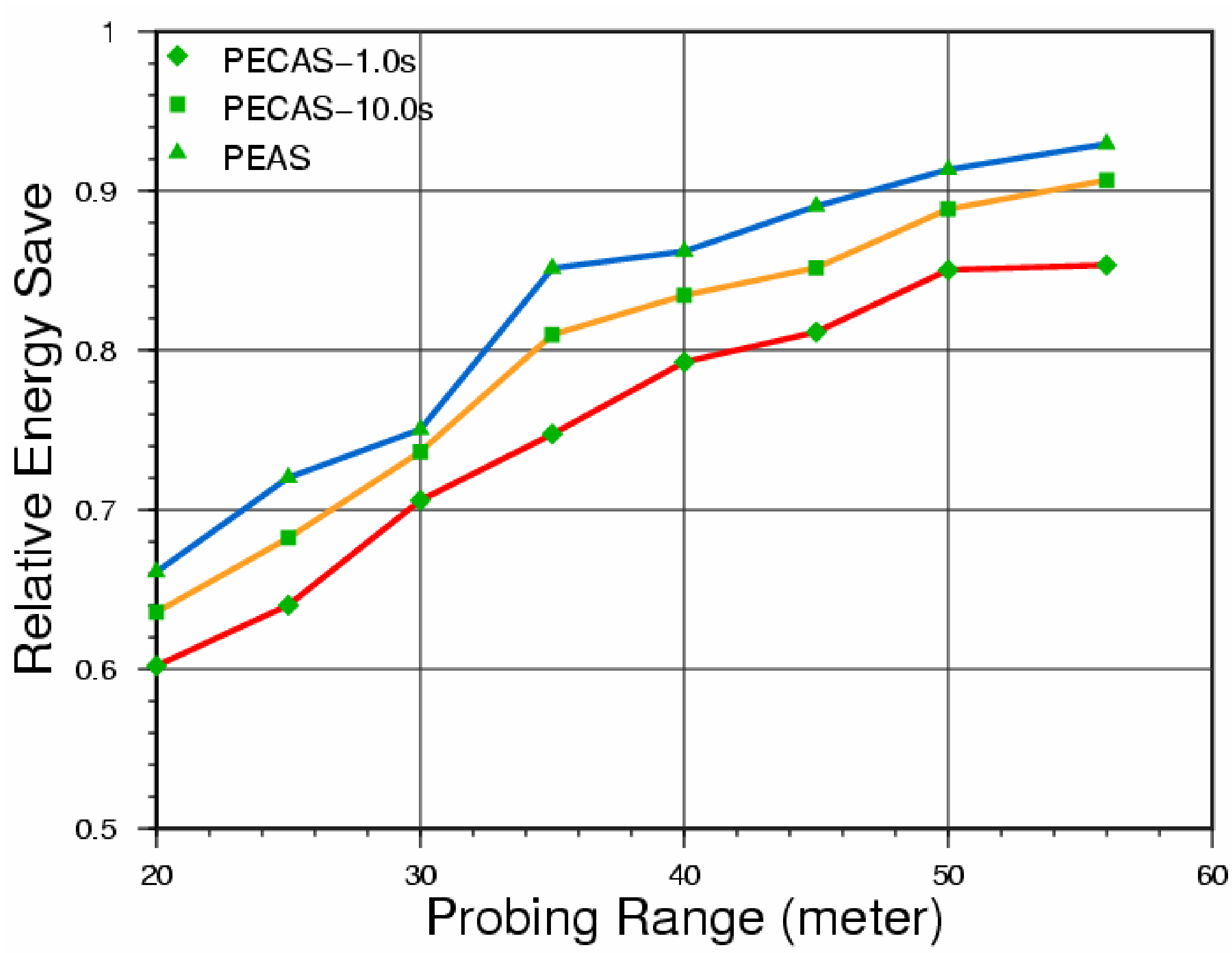
Simulation Setup:

- 800 nodes,
- transmission range = 55.9 m,
- sensing range = 20m
- target speed = 10 m/s

Performance Metric:

- total energy consumed

Performance Evaluation: Relative Energy Save



Conclusions & Future Work

- Contributions and Inferences:
  - Proposed and quantified a new metric of QoSv
  - Proposed and enhanced sleeping method – PECAS
    - Sleeping methods can not only save power but also optimize sensor deployment
  - Proposed a new collaborative power saving approach for target tracking using state transitions
    - Could achieve significant energy savings
  - Location information can be used to achieve better sleeping
- Following Work
  - Extend our work to multiple targets
  - Use "virtual patrol" for better surveillance and sleeping