On Setting up Energy-Efficient Paths in Wireless Sensor Networks

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Outline

- Motivation of this work
- Modeling the transmitter power setting problem in WSNs
- Implementation issues
- Experimental results
- Future work and conclusions

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- **Motivation of this work**
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Differences between WSNs MANETs

- Features of the network traffic
  - WSN: usually many-to-one traffic
  - MANETs: usually unicasting traffic
- Nature of network dynamics
  - MANETs: nodes are mobile
  - WSN: the sink may be mobile
- Resource constraints
  - WSN: less energy resource

Transmitter Power Control

- What transmitter power control is?
  - Set the transmitter power levels
    - Resulting in different network topology
- Why it is necessary?
  - Save energy consumed in communications
- The prerequisite
  - The transmitter power levels CAN be set:
    - True in most sensor node implementations

Transmitter Power Control

- Current research in this area
  - Providing energy-efficient unicasting, broadcasting and multicasting
  - Network connectivity analysis
  - Network lifetime analysis
- Our objective
  - Providing energy-efficient sensor-to-sink communications

The issues we address

- Modeling our objective
  - Formulate the transmitter power setting problem
- Finding the solution
  - Theoretical solution
  - Implementation: low overhead

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- Motivation of this work
- **Modeling the Transmitter Power Setting Problem**
- Implementation Issues
- Experimental Results
- Future Work and Conclusion
- Signal Fading Model
  -

Wireless Communication Model

- Signal fading model

$$Pr(u) \geq c \cdot (D(u, v))^n$$

  - u: source node
  - v: destination node
  - c: constant
  - D(u, v): physical distance between these two nodes
  - n: signal fading factor
    - Typically in interval (2, 5)

Network Model

- Model the network as a graph G(V, E)
  - V: sensor nodes
  - E: wireless links connected at maximal transmitter power settings
- X(u): u in V
  - The approximate position of each node u
  - How to obtain it?
    - GPS
    - Many Localization Algorithms

Network Model

- Model the resulting network as a subgraph G'(V, E') of G(V, E)
  - E': the wireless links connected with a transmitter power setting scheme.
  - Why it is a subgraph of G?
    - Each e' in E' is a member of E
  - G'(V, E') is a directed graph. Why?

Energy Consumption Model

- Energy consumptions along a traffic path
  - $\overrightarrow{\ell}(u_1, s)$: a sensor-to-sink path along u1, u2, …, ui, s

$$\sum_{n=1}^{i}(\gamma Pr(u_n)) + \sum_{n=2}^{i}(\gamma Rr(u_n) + Ps(u_n))$$
$$+\gamma Rr(s) + Ps(s),$$

  - Pr: transmitter power
  - Rr: receiver power
  - Ps: energy required to process a packet
  - γ: constant

Energy Consumption Model

- Energy consumptions along a traffic path

$$\gamma \sum_{n=1}^{i} (Pr(u_n) + \beta)$$

  - β : constant

Energy Consumption Model

- Path cost

$$\omega(\overrightarrow{\ell}) = \gamma \sum_{n=1}^{i} (Pr(u_n) + \beta)$$

- Cost function of an edge e(u, v) in G and G'

$$\gamma(c \cdot (D(u,v))^n + \beta)$$

- Node cost: $\eta(u)$
  - The minimal value of the path cost of the known paths to the sink

Transmitter Power Setting Problem

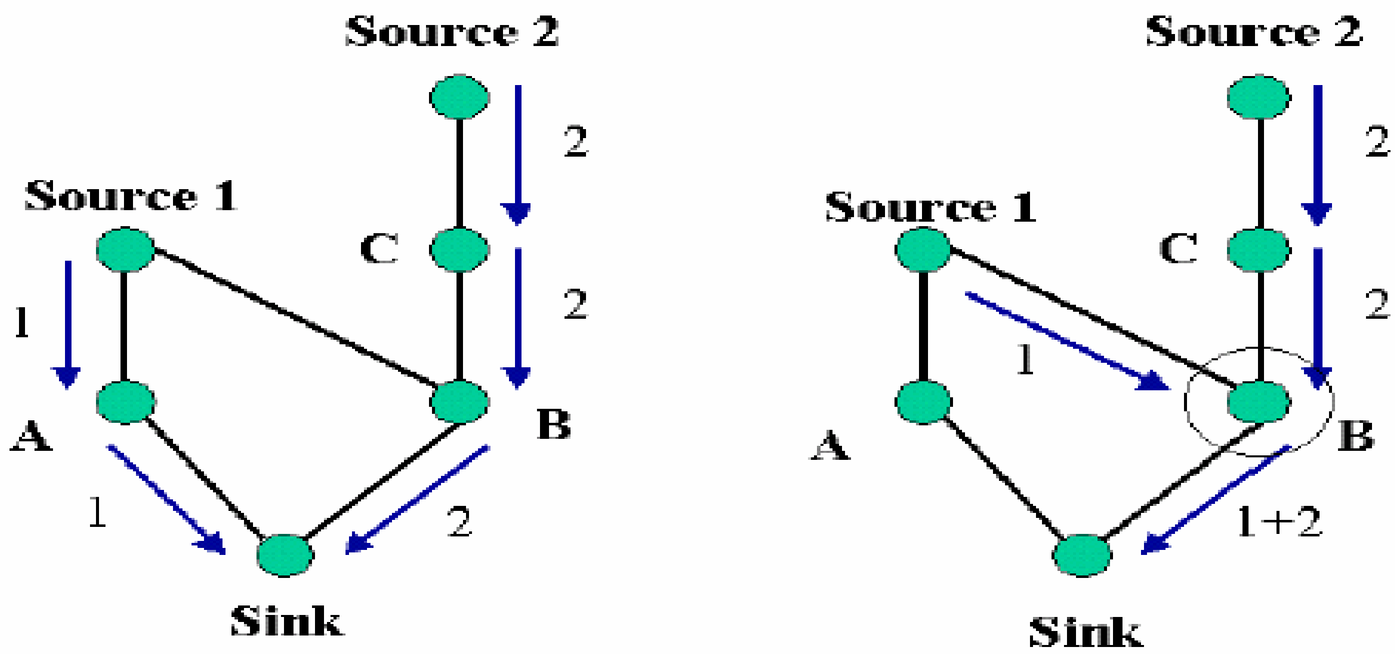
Problem 1: Given the graph G(V, E) and a sink s ($s \in V$), compute $P(V)$ such that in the resulting $G'(V, E')$, there exists at least one path $\overrightarrow{\ell}(u, s)$ from each node u ($u \in V$) to the sink s and the $\eta(u)$ is minimized. ■

P(V): The Transmitter Power level of each node in set V

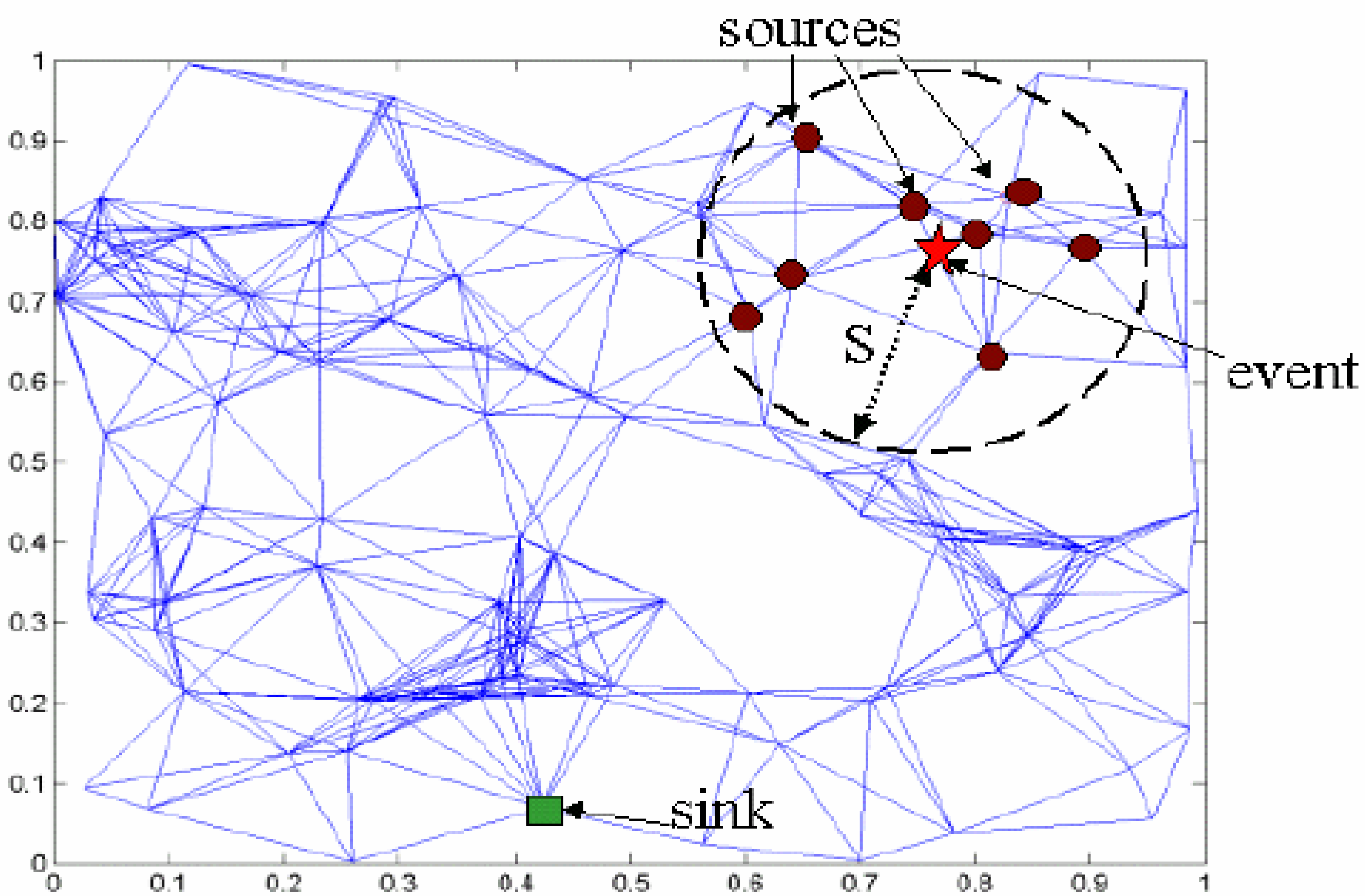
Transmitter Power Setting Problem

- Why find energy-efficient paths from an arbitrary node to the sink?
  - No in-network data aggregation/fusion
    - Simply many-to-one traffic
  - Otherwise
    - Reverse-Multicasting
      - Minimum Steiner Tree
      - NP-Complete
    - Why we still find energy-efficient paths from an arbitrary node to the sink?

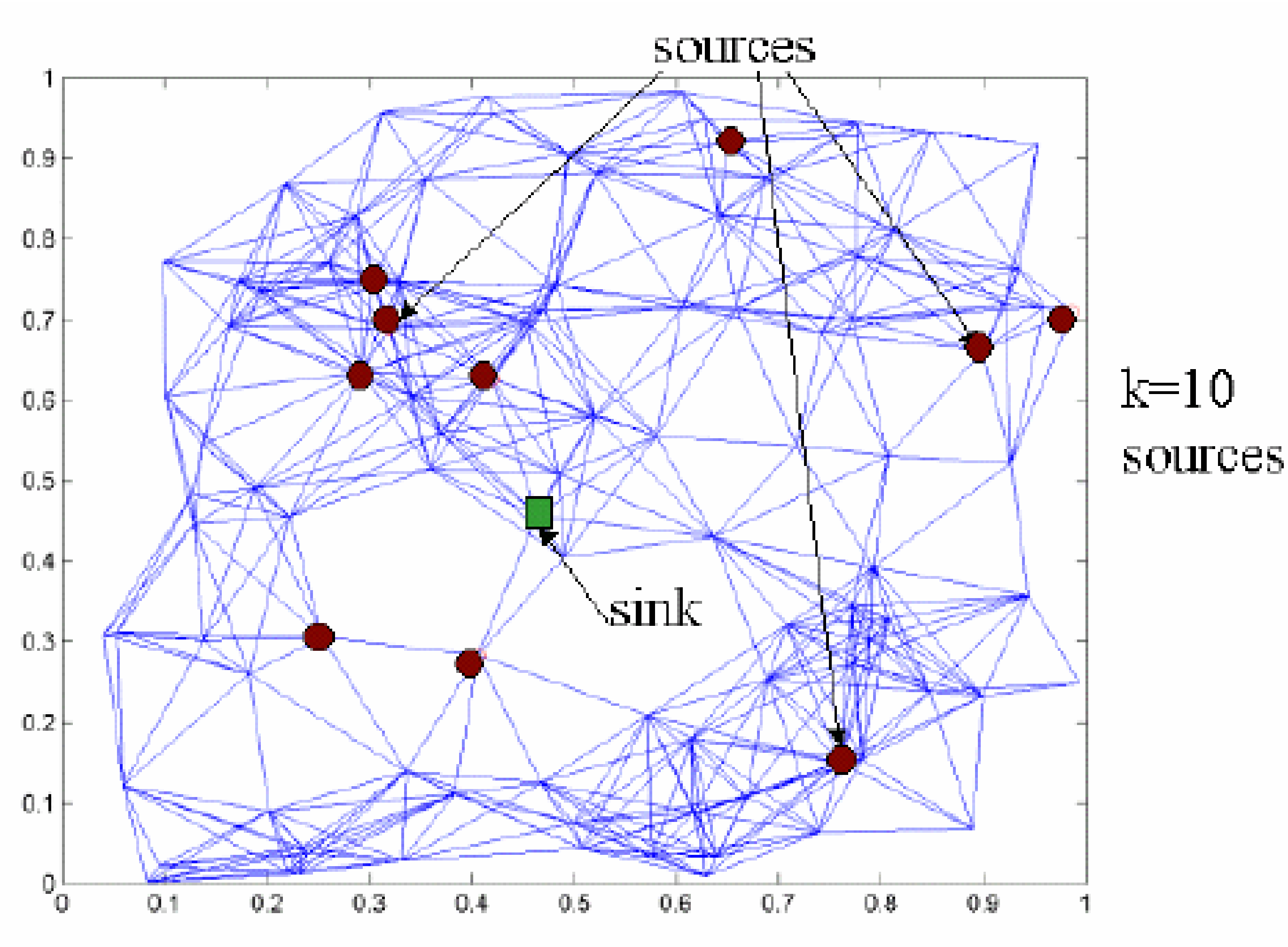
Illustration of Data Aggregation/Fusion



Source Placement Model 1



Source Placement Model 2



Theoretical Solution

- Find a spanning tree
  - The Tree is rooted at the sink
  - The path from each node to the sink is the shortest path
- Set the transmitter power level of each node so that it can just reach the adjacent downstream node along the path

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Implementation Considerations

- No global picture
  - The algorithm is distributed
  - The algorithm employs localized information
- Low overhead
  - The algorithm exchanges as small number of packets as possible

The Configuration Packet

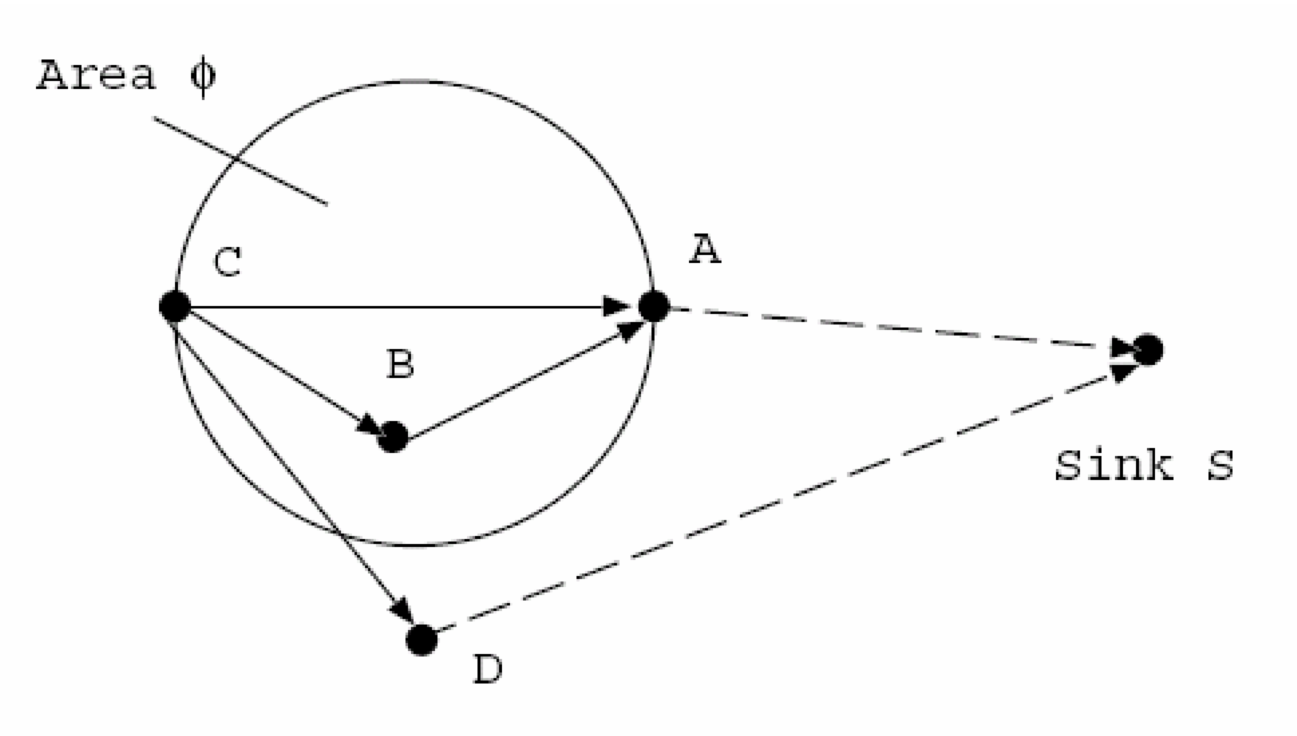
- Location of the sender
- Node cost of the sender

BOU: the Basic Approach

- The sink initially send a configuration packet with node cost equal to zero
- Each in-network node firstly set its node cost as $+\infty$
- Each node that receives a configuration packet calculates the path cost along the sender to the sink
  - If the path cost is greater than its current node cost, drop the packet
  - Otherwise,
    - The path along the sender to the sink is the known shortest path
    - Let its node cost equal to this path cost
    - Broadcast another configuration packet with the updated node cost

The Inadequacy

- It causes explosive broadcasting



How to Avoid Meaningless Broadcasting

- Wait before broadcasting, upon the update of the node cost
  - How to determine the waiting time?

Determining the Waiting Time

- The waiting time should be proportional to the probability ρ that a better path will be known in the future.
- BOU-W: An improvement of BOU
  - BOU-W: wait before broadcast, on update.
  - The waiting time is: $\alpha \cdot \rho$
    - α is a constant whose value is determined empirically

Obtain the Probability

Problem 2: Given

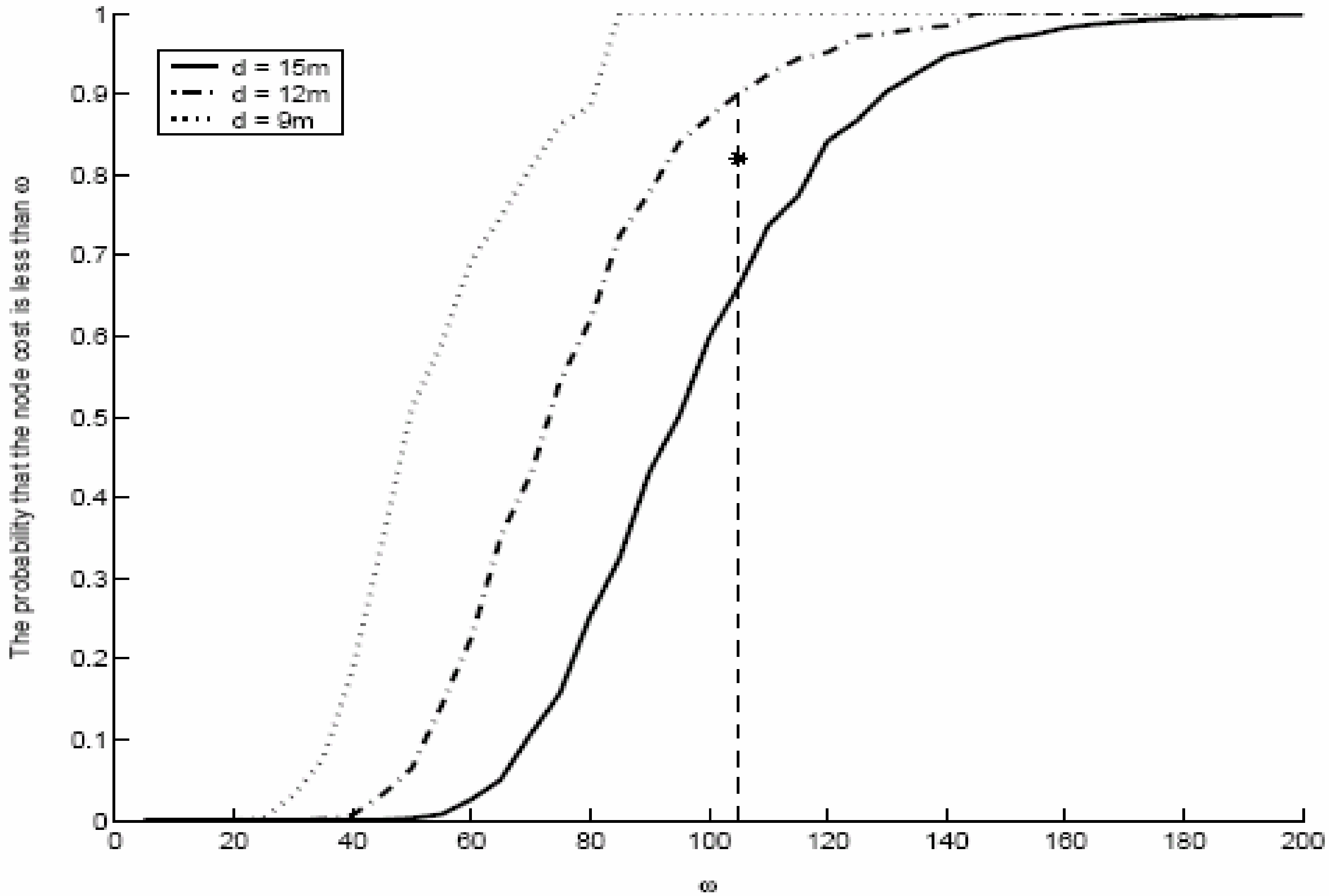
- A graph G(V, E), a sink s ($s \in V$), and the cost function of an edge of the graph described in Equation (6);
- The probability density function $P_x(X)$ of the location of each node u ($u \in V$) where X is the possible physical location;
- The deterministic location x of a node m ($m \in V$, $m \neq s$) and the deterministic location y of the sink s;
- The cost $\omega(\overrightarrow{\ell})$ of a path $\overrightarrow{\ell}$ from node m to the sink s;

Compute the probability ρ that there exists a path $\overrightarrow{\ell'}$ from the node m to the sink s other than $\overrightarrow{\ell}$ such that the cost of $\overrightarrow{\ell'}$, $\omega(\overrightarrow{\ell'})$, satisfies $\omega(\overrightarrow{\ell'}) < \omega(\overrightarrow{\ell})$.■

Obtain the Probability

- Mathematical Solution
  - Very hard
- Numerical Solution
  - Monte Carlo method

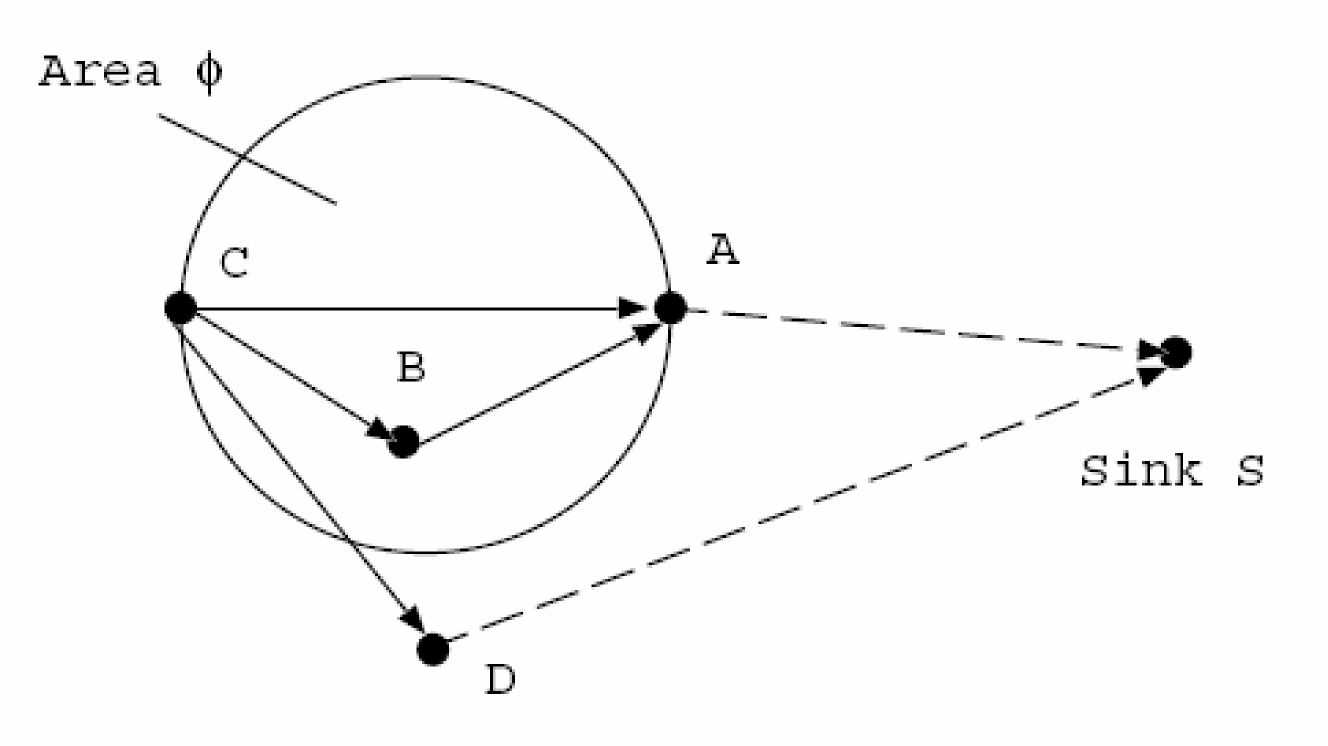
Example Distributions



BOU-W: Comments

- What is needed?
  - The location of the sink
  - The statistical data
- The shortcomings
  - Huge volume of statistical data
    - Not practical due to the hardware constraint
  - If the node deployment scheme cannot be well modeled, emulations cannot be conducted

BOU-WA: An approximate solution



BOU-WA: An approximate solution

- Calculate the probability that node B exists
  - Very simple

BOU-WA: An approximate solution

- What's needed
  - The location of the sender
  - The network area and the total node number
- How it works
  - We will study in experimental work

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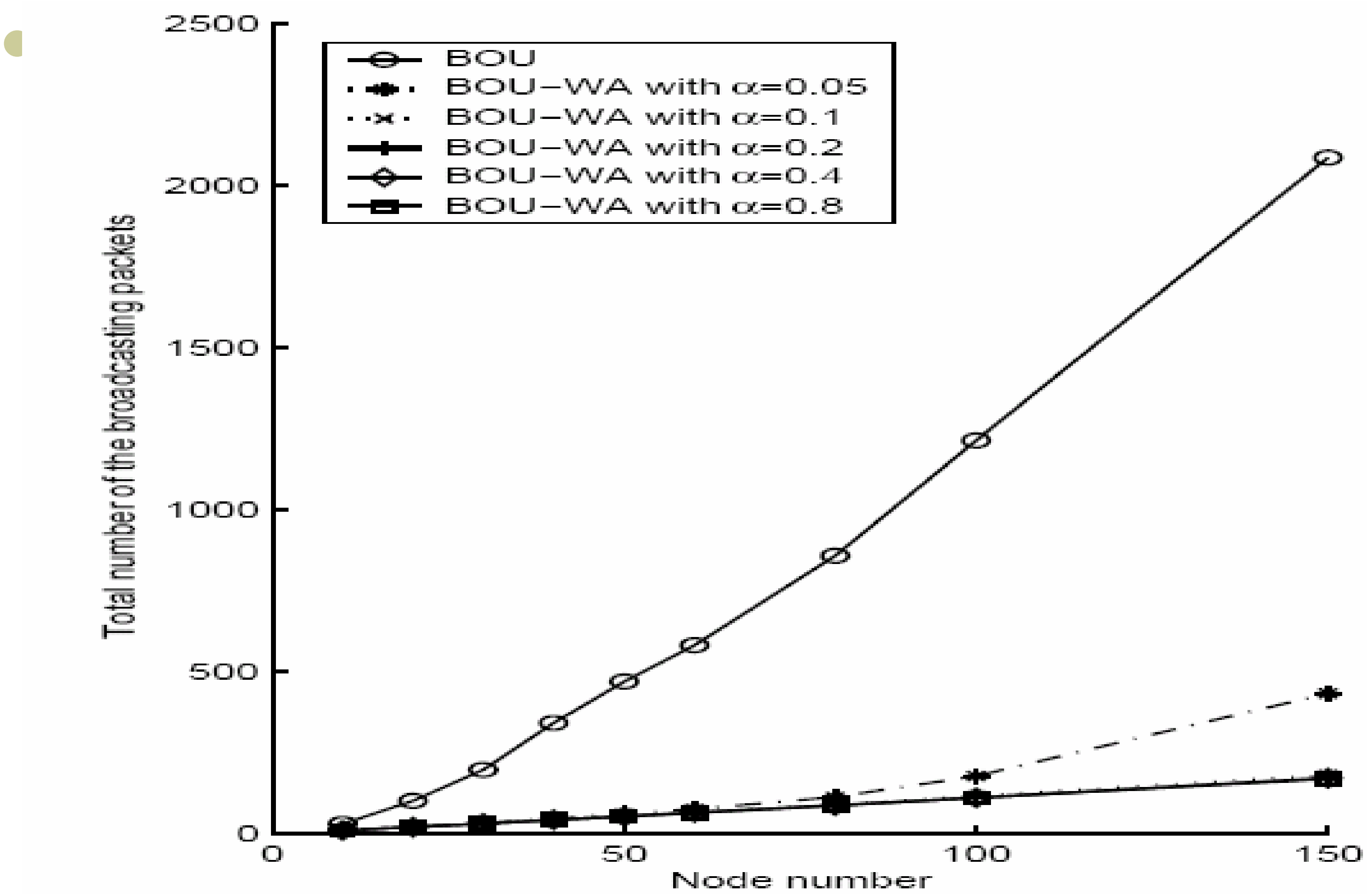
The Simulation Network

Area of sensor field	100m*100m
MAC Protocol	IEEE 802.11 without CTS/RTS and ACK
Transmitter Power	0.660W
Receiver Power	0.395W
Wireless Communication Model	Free Space
Packet length	36 bytes

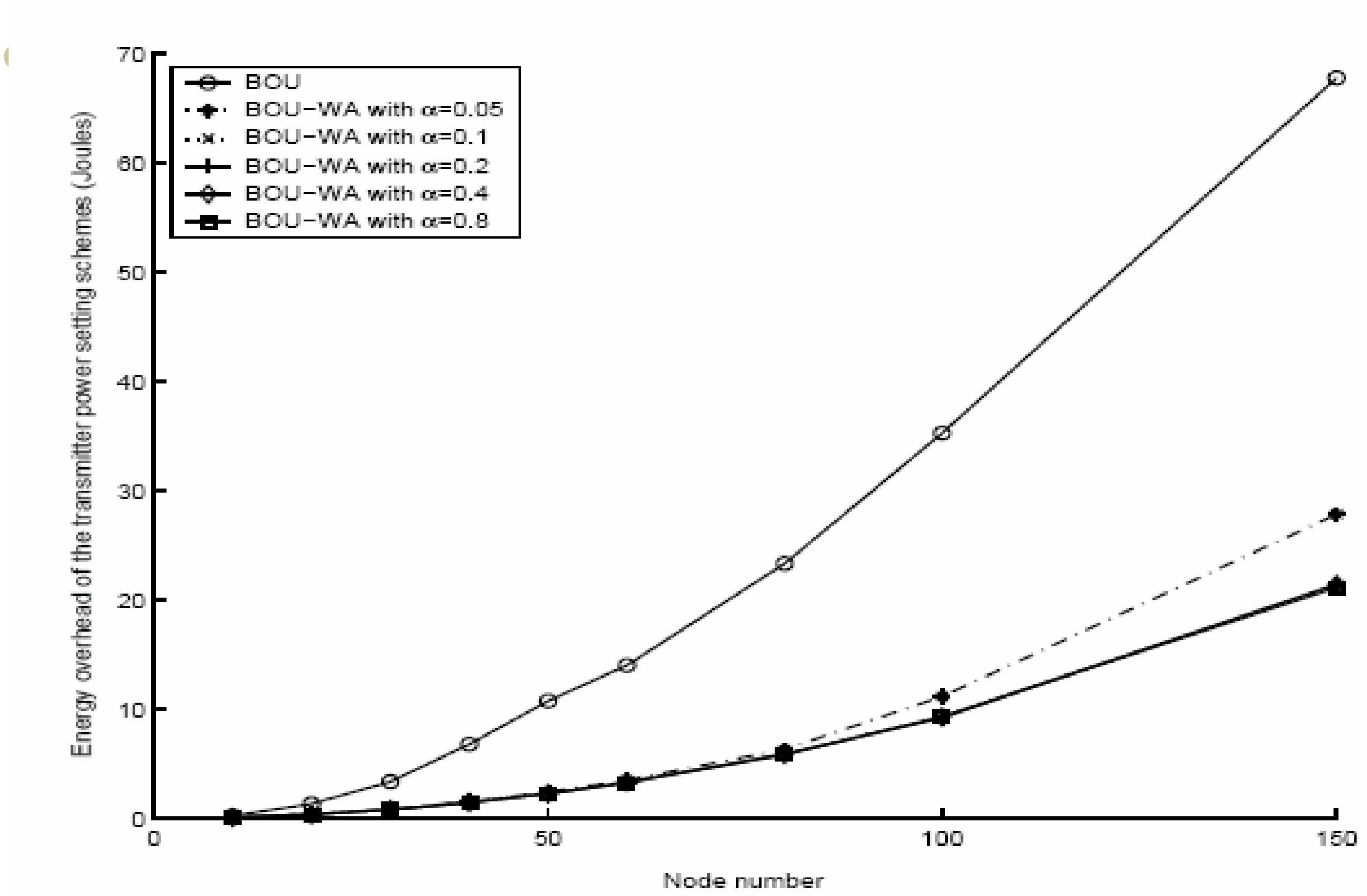
Evaluation of Overhead

- Experiment Design
  - Comparing BOU-WA with BOU
    - Energy consumption overhead
    - Converging time

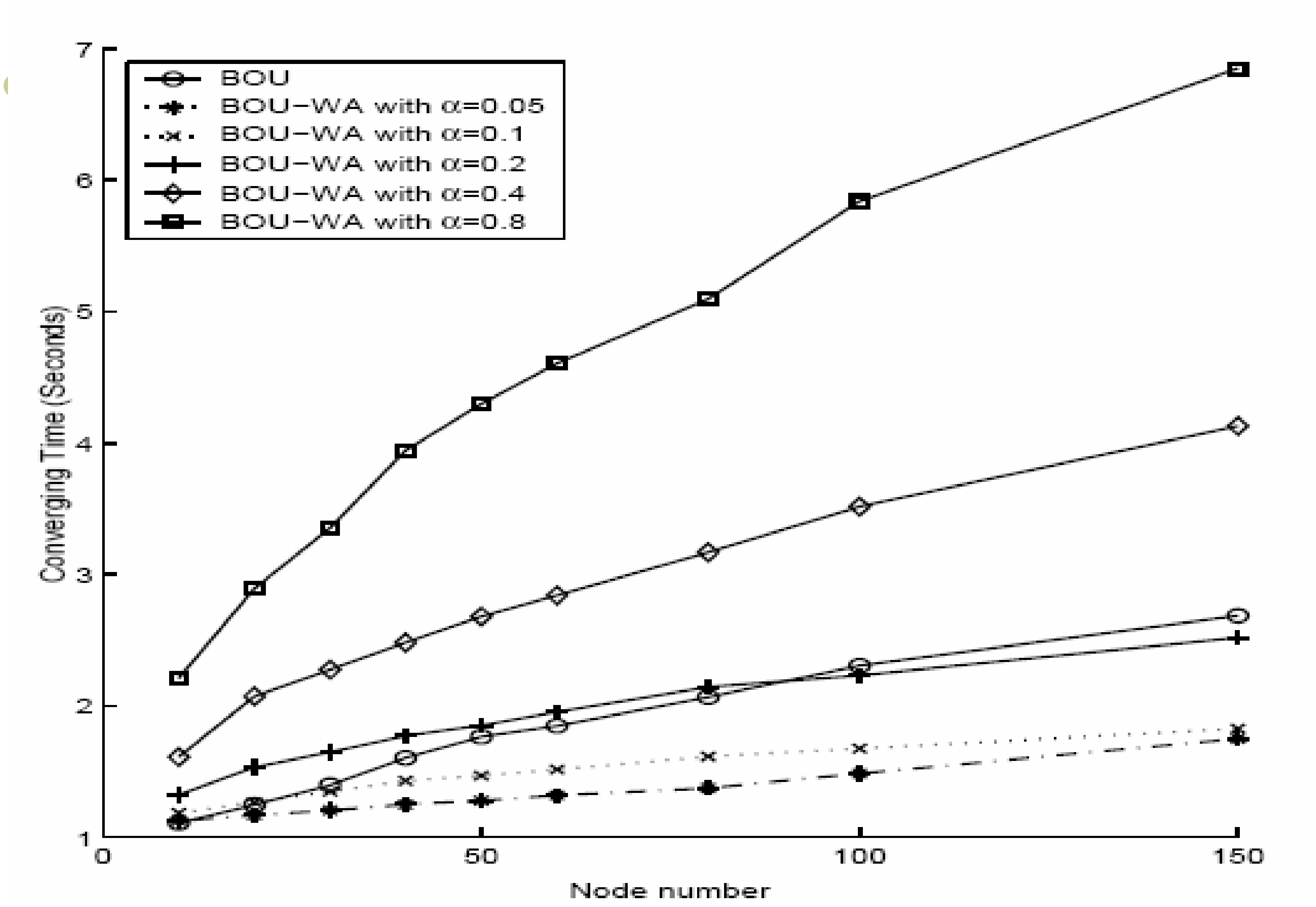
Evaluation of Overhead



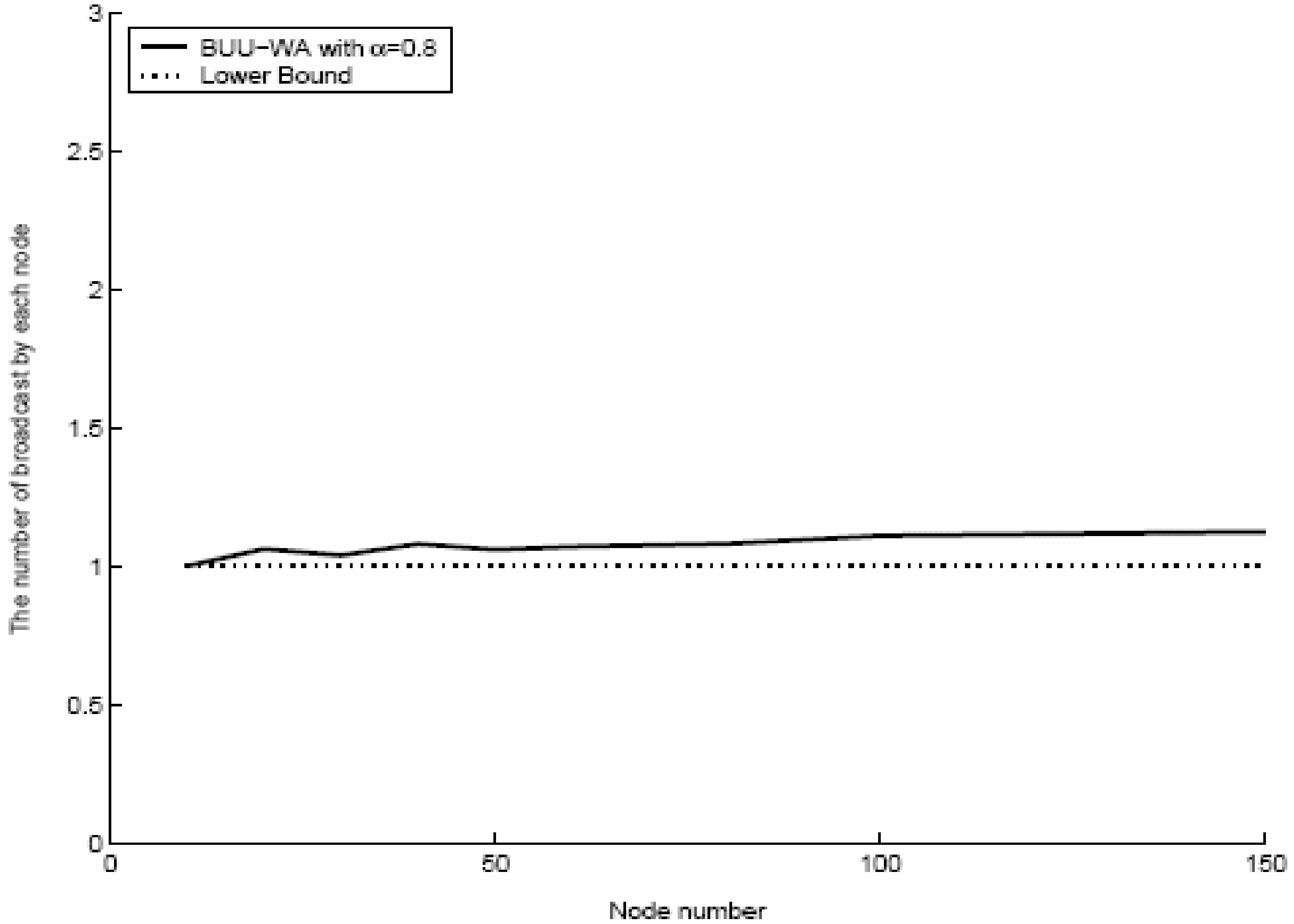
Evaluation of Overhead



Evaluation of Converging Time



Further discussion



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Future work

- How does BOU-WA perform in real application scenarios?
- Is there any room to improve the modeling work of the transmitter power setting problem.

Conclusion Remarks

- We model the transmitter power setting problem for WSNs
- We investigate the implementation issues of the solution and provide a low overhead algorithm called BOU-WA
- Experimental results show the advantages of BOU-WA

Q & A

Thank You