A survey of solutions to the coverage problems in wireless sensor networks

Po-Yu Chen

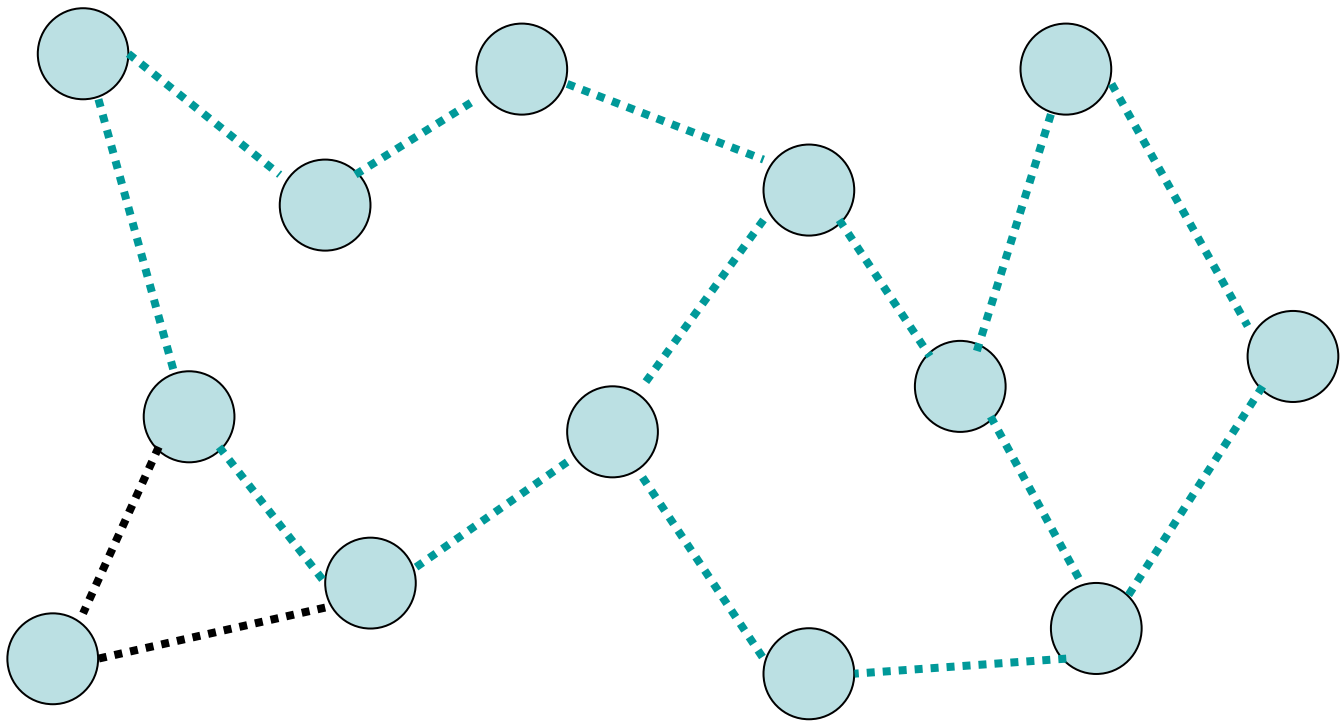
Multimedia Network Lab. NTHU

Outline

- Introduction
- *Surveillance and Exposure part-1*
- Coverage and Connectivity part-2
- Discussion
- References

Introduction

- Sensor networks



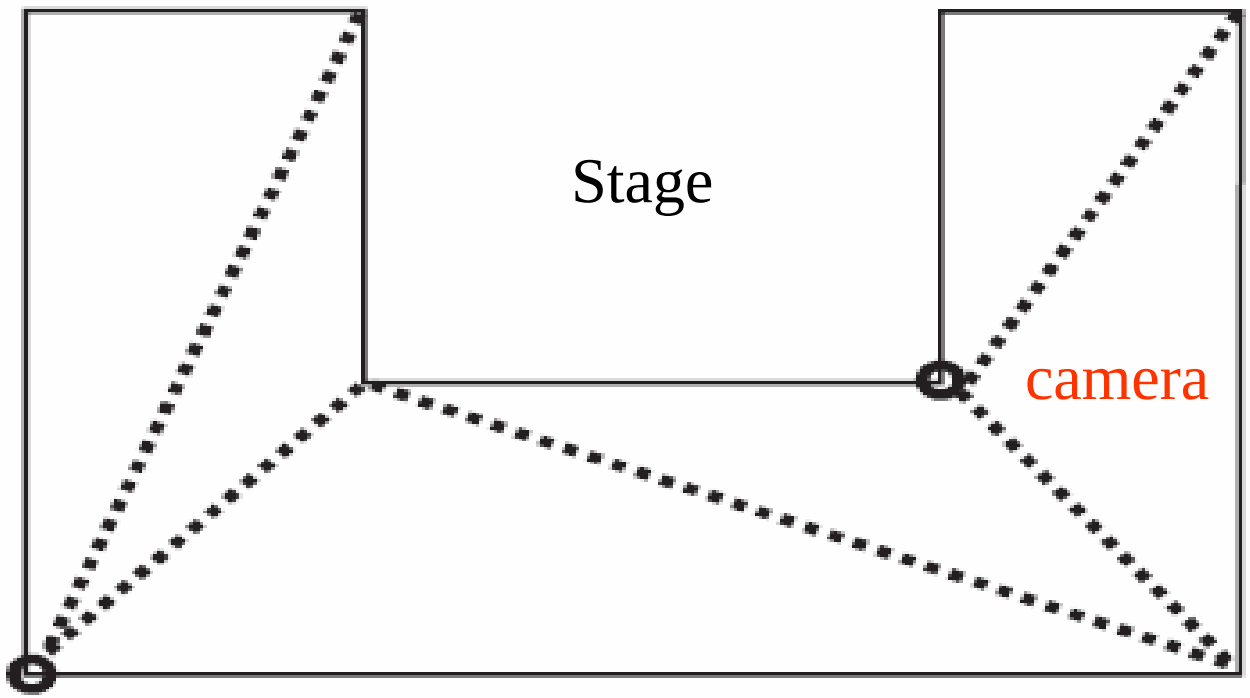
Introduction

- Sensor nodes
  - Small size
  - Low power consumption
  - Few functions
- Design issues
  - PHY and MAC Layers
  - Routing and Transport Protocols
  - Localization and Positioning applications
  - Coverage and Connectivity Problems

Related Geometric Problems

- Art Gallery Problem
  - How many cameras are needed
  - Where these cameras should be deployed
- The galley is usually modeled as a simple polygon on 2D plane
- In a 3D space, this problem is NP
  - [14] proposes a suboptimal solution.

Art Gallery Problem

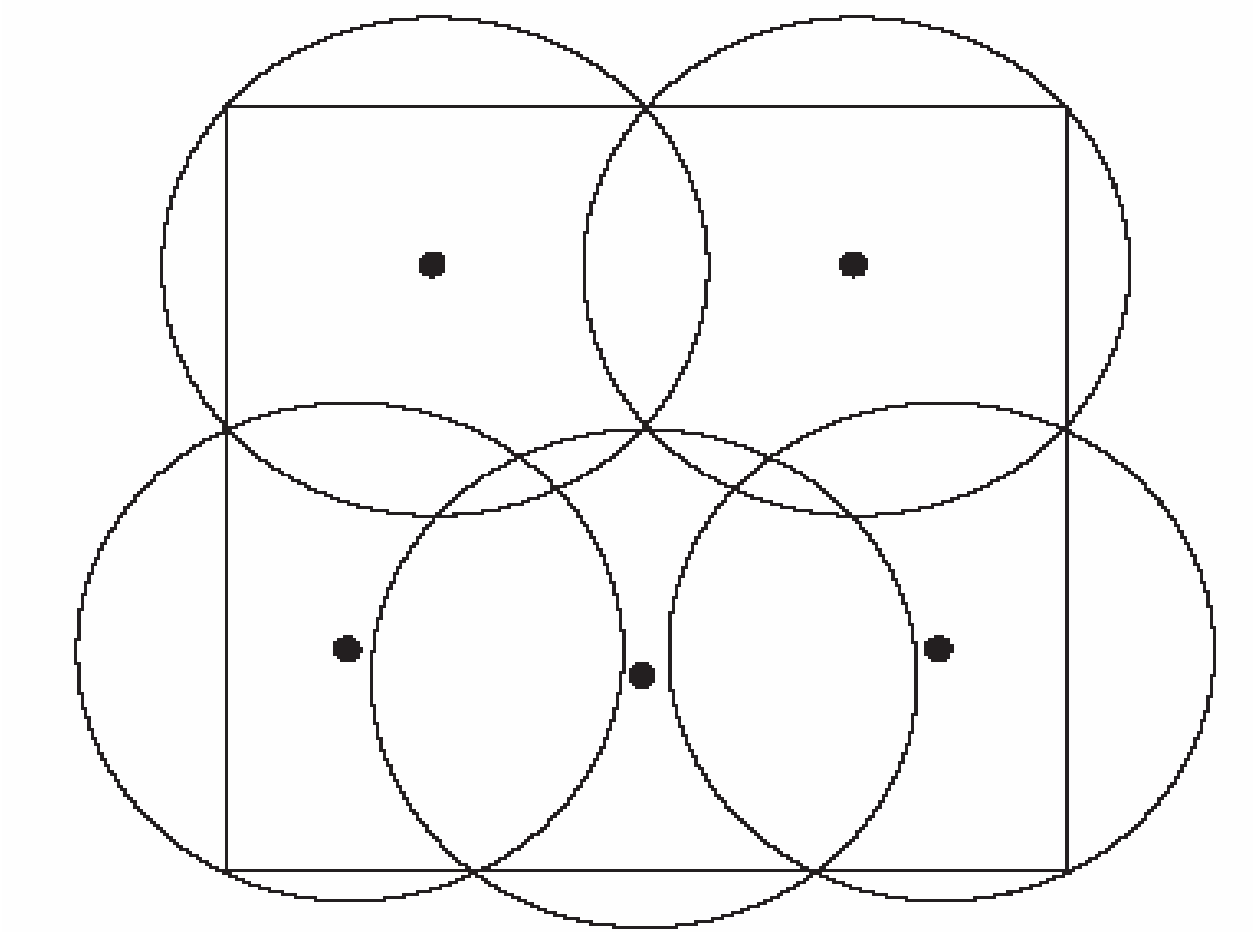


- Triangulating the polygon
- Number of cameras = n/3

Related Geometric Problems

- Circle Covering Problem
  - To arrange identical circles on a plane that can fully cover the plane
  - Given a fixed number of circles, the goal is to minimize the radius of circles

Circle Covering Problem



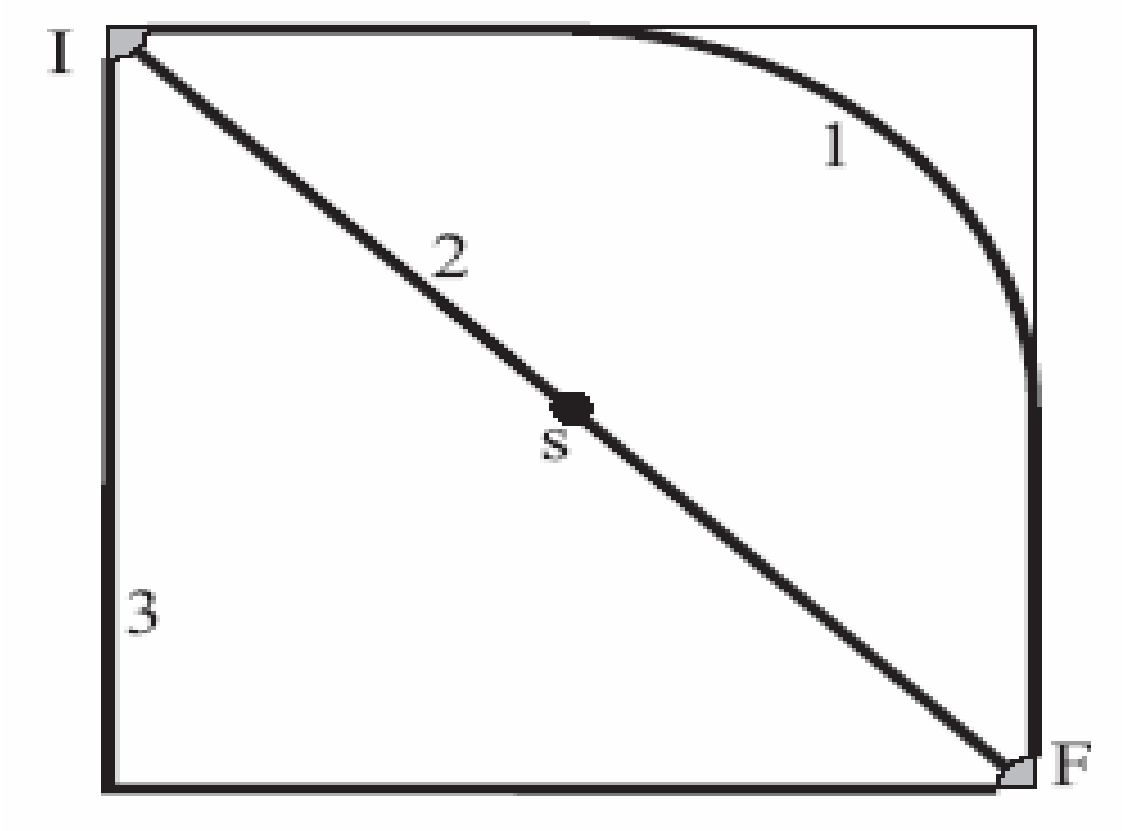
Surveillance and Exposure

- To find a path connecting these two points which is best and worst monitored by sensors
- Maximal branch path [1][5] -- Voronoi diagram
  - The distance form any point to the closest sensor is maximized
- Maximal support path [1][5] -- Delaunay triangulation
  - The distance form any point to the closest sensor is minimized

Surveillance and Exposure

- Exposure: the sensing ability of sensors can be improved as the sensing time increases
  - Minimal exposure path [1][2][6][7]
    - Worst coverage of a sensor network
  - Maximal exposure path [1][3]
    - Best coverage of a sensor network
- They also use voronoi diagram and delaunay triangulation to partition the sensing filed

Example of exposure



Coverage and Connectivity

- An area is covered by some sensor nodes, but these nodes are uncertainly connecting with each other
- Some works consider the coverage and connectivity of sensor networks [10, 11, 12, 13]

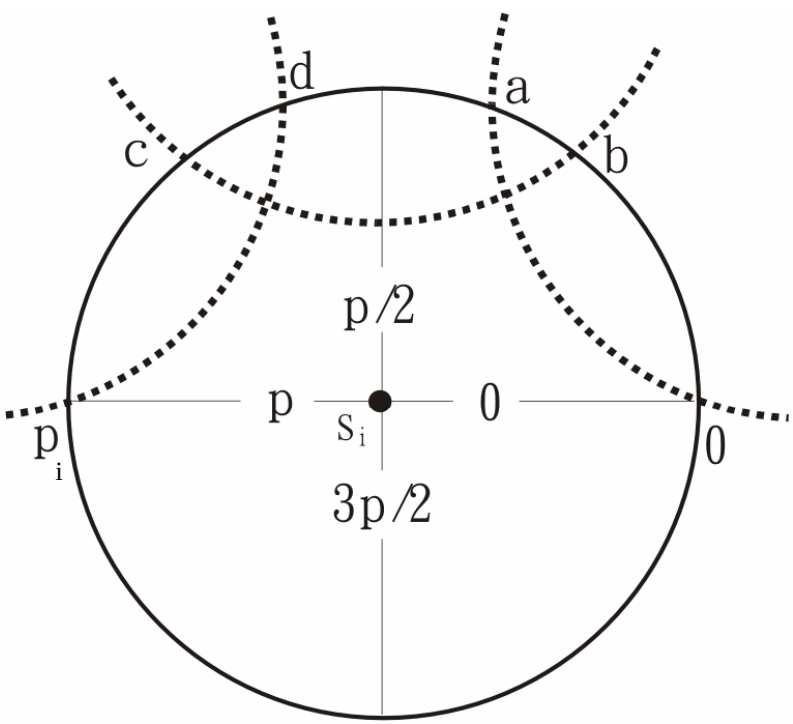
Coverage and Connectivity

- Issues
  - Sensing range
  - Network connectivity
  - Network density control
  - Energy conserving

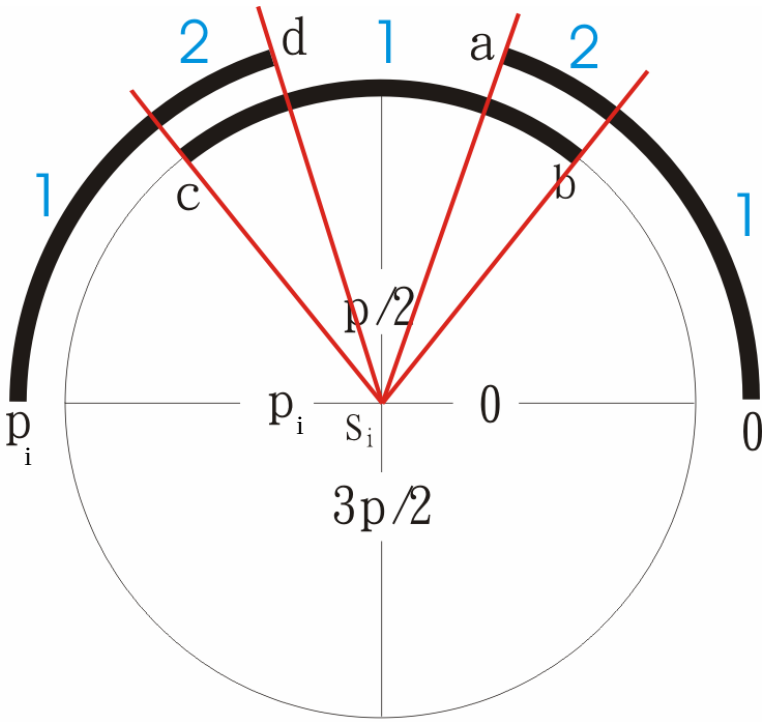
Proposed solutions (1)

- In [10], the coverage problem is formulated as a decision problem.
- *k-covered*
  - Every point in target area is covered by at least k sensors, where k is a given parameter
- As long as the perimeters of sensors are sufficient covered, the whole area is sufficiently covered

K-covered



(a)



(b)

Proposed solutions (2)

- Under what condition coverage may imply connectivity?
  - Communication range > 2 * Sensing range
- In [12], authors study the relationship between coverage and connectivity, if a target area is *k-covered*
- The author proves that if a region is *k-covered*, then the sensor network is *k-connected*

Proposed solutions (2)

- Coverage Configuration Protocol (CCP)
  - It provides different degrees of coverage and maintains communication connectivity
  - K-covered eligibility algorithm
    - To select the active node and control the degree of coverage

Proposed solutions (2)

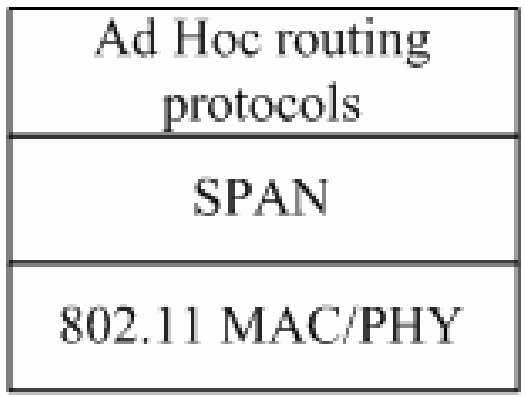
- All nodes are initially in the *ACTIVE* state
- ACTIVE
  - Nodes maintain neighbor tables and execute the coverage eligibility algorithm
- SLEEP
  - Redundant nodes will switch to SLEEP state
  - Nodes weak up periodically to LISTEN
- LISTEN
  - Nodes receive messages and evaluate their eligibility

Proposed solutions (2)

- Communication range < 2 * Sensing range
  - Integrate CCP with SPAN
  - Eligibility rule for inactive nodes
    - An inactive node will be eligible to become active if it is eligible according to the eligibility rule of *SPAN or CCP*
  - Eligibility rule for active nodes
    - An active node will withdraw if it satisfies the eligibility rule of neither *SPAN nor CCP*

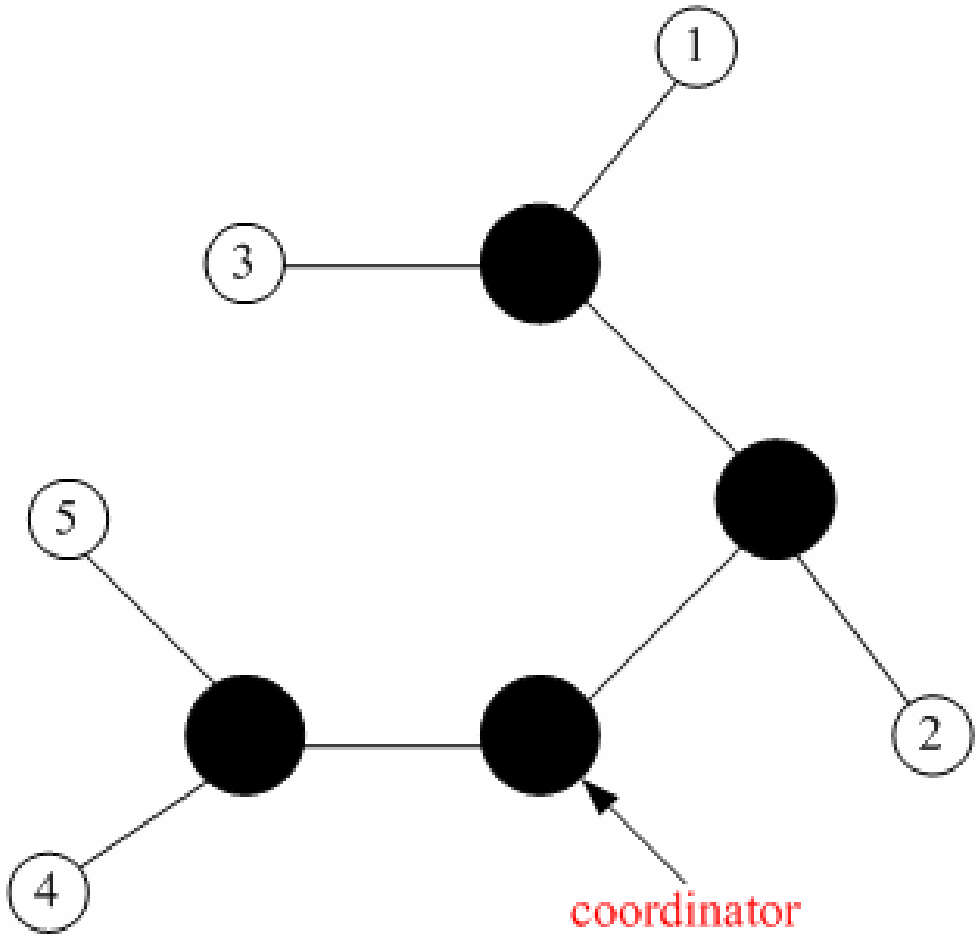
SPAN

- SPAN is a connectivity-maintaining protocol

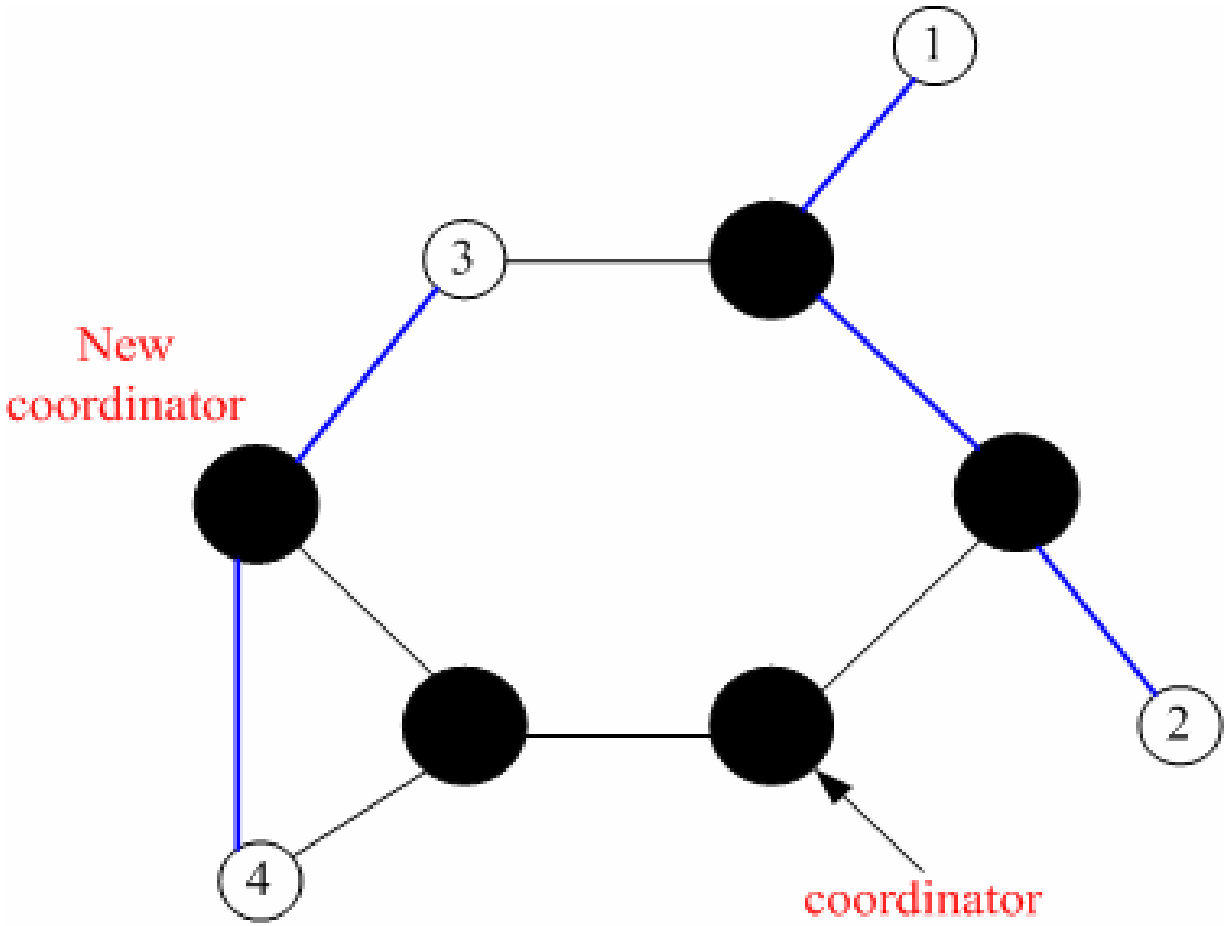


- Coordinator eligibility rule
  - If two neighbors of a non-coordinator node cannot reach each other directly or via one or two coordinators, the node should become a coordinator

SPAN



SPAN



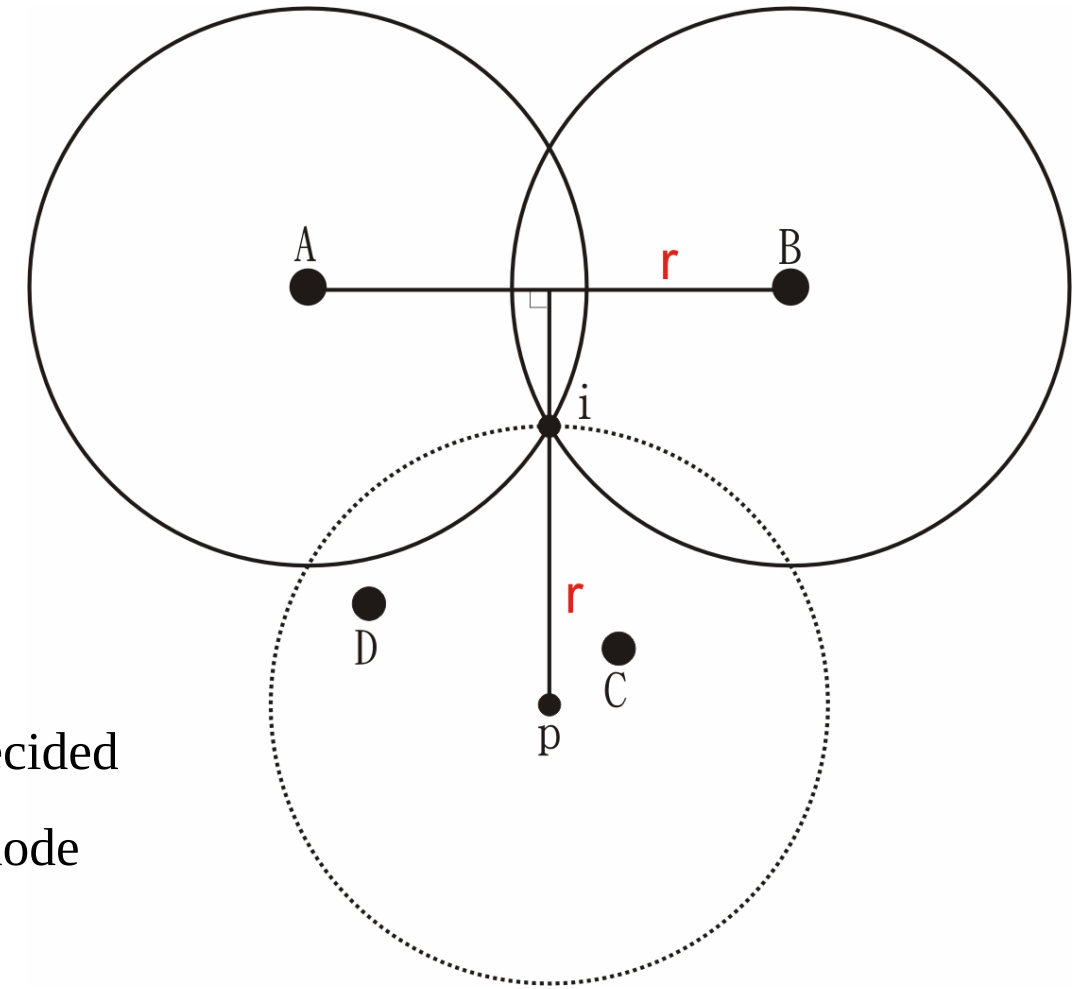
Proposed solutions (2)

- CCP eligibility rule guarantees that the region is covered to the required degree
- SPAN will activate extra nodes so that every node can reach a active node within its communication range

Proposed solutions (3)

- Optimal Geographical Density Control (OGDC)
  - Using minimum nodes to maintain coverage and connectivity
  - To reduce the overlapping areas that are covered by nodes in ON state
  - A decentralized algorithm
  - Communication range > 2 * Sensing range

OGDC



- States:
  - ON, OFF, Undecided
- Node A is a starting node

Summary

- Coverage may imply connectivity if
  - Communication range > 2 * Sensing range
- Maintaining coverage and connectivity
  - CCP
  - CCP with SPAN
  - OGDC

Discussion

- Coverage problem in 3D space
  - The sensing region is modeled by a 3D ball [14]
- Coverage preserving and Energy conserving
  - Self-configuration protocol

References

[1] S. Adlakha and M. Srivastava. Critical density thresholds for coverage in wireless sensor networks. In *IEEE Wireless Communications and Networking Conf. (WCNC)*, pages 1615 – 1620, 2003.

[2] Q. Huang. Solving an open sensor exposure problem using variational calculus. Technical Report WUCS-03-1,Washington University, Department of Computer Science and Engineering, St. Louis, Missouri, 2003.

[3] X.-Y. Li, P.-J. Wan, and O. Frieder. Coverage in wireless ad hoc sensor networks. *IEEE Trans. Comput.*, 52(6):753–763, June 2003.

[4] B. Liu and D. Towsley. On the coverage and detectability of wireless sensor networks. In *WiOpt'03: Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks*, 2003.

[5] S. Meguerdichian, F. Koushanfar, M. Potkonjak, and M. B. Srivastava. Coverage problems in wireless ad-hoc sensor networks. In *IEEE INFOCOM*, pages 1380–1387, 2001.

[6] S. Meguerdichian, F. Koushanfar, G. Qu, and M. Potkonjak. Exposure in wireless ad-hoc sensor networks. In Proceedings of the 7th International Conference on Mobile Computing and Networking (MobiCom '01), Rome, Italy, (Best Student Paper Award), pages 139-150, July 2001.

[7] S. Megerian, F. Koushanfar, G. Qu, G. Veltri, and M. Potkonjak. Exposure in wireless ad-hoc sensor networks: Theory and practical solutions. Journal of Wireless Networks, 8(5):443{454, September 2002. ACM Kluer Academic Publishers.

References

[8] S. Shakkottai, R. Srikant, and N. Shroff. Unreliable sensor grids: coverage, connectivity and diameter. In *IEEE INFOCOM*, pages 1073 – 1083, 2003.

[9] H. Zhang and J. C. Hou. Maintaining sensing coverage and connectivity in large sensor networks. In *NSF International Workshop on Theoretical and Algorithmic Aspects of Sensor, Ad Hoc Wireless, and Peer-to-Peer Networks*, 2004.

[10] C.-F. Huang and Y.-C. Tseng. The coverage problem in a wireless sensor network. In *ACM Int'lWorkshop onWireless Sensor Networks and Applications (WSNA)*, pages 115–121, 2003.

[11] S. Shakkottai, R. Srikant, and N. Shroff. Unreliable sensor grids: coverage, connectivity and diameter. In *IEEE INFOCOM*, pages 1073 – 1083, 2003.

[12] X.Wang, G. Xing, Y. Zhang, C. Lu, R. Pless, and C. Gill. Integrated coverage and connectivity configuration in wireless sensor networks. In *ACM Int'l Conf. on Embedded Networked Sensor Systems (SenSys)*, pages 28–39, 2003.

References

[13] H. Zhang and J. C. Hou. Maintaining sensing coverage and connectivity in large sensor networks. In *NSF International Workshop on Theoretical and Algorithmic Aspects of Sensor, Ad Hoc Wireless, and Peer-to-Peer Networks*, 2004.

[14] C.-F. Huang, Y.-C. Tseng, and L.-C. Lo. The coverage problem in three-dimensional wireless sensor networks. Submitted to GLOBECOM'04.

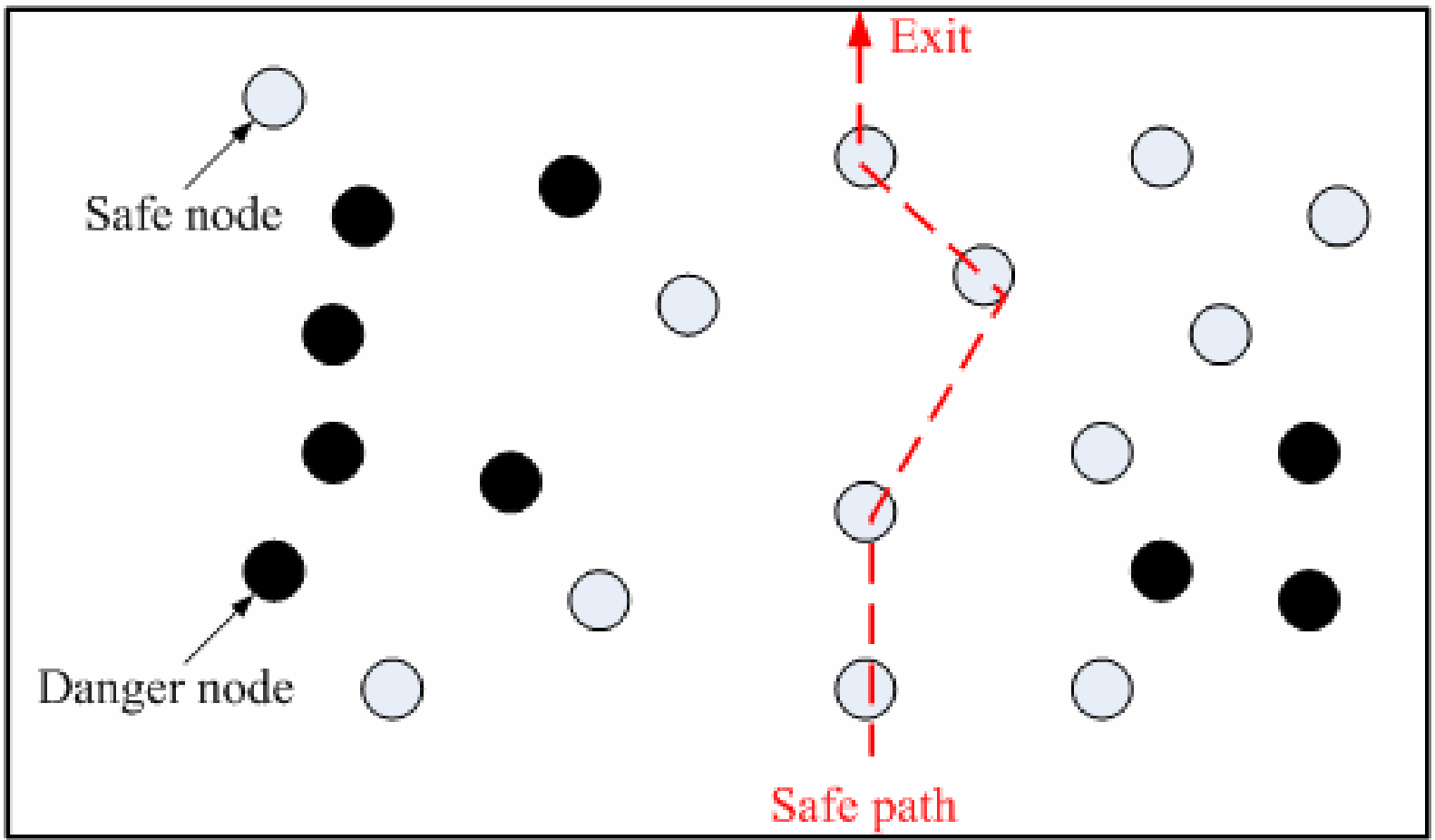
Project progress report

- LeGoJOS is already integrated with Stargate
- Testing

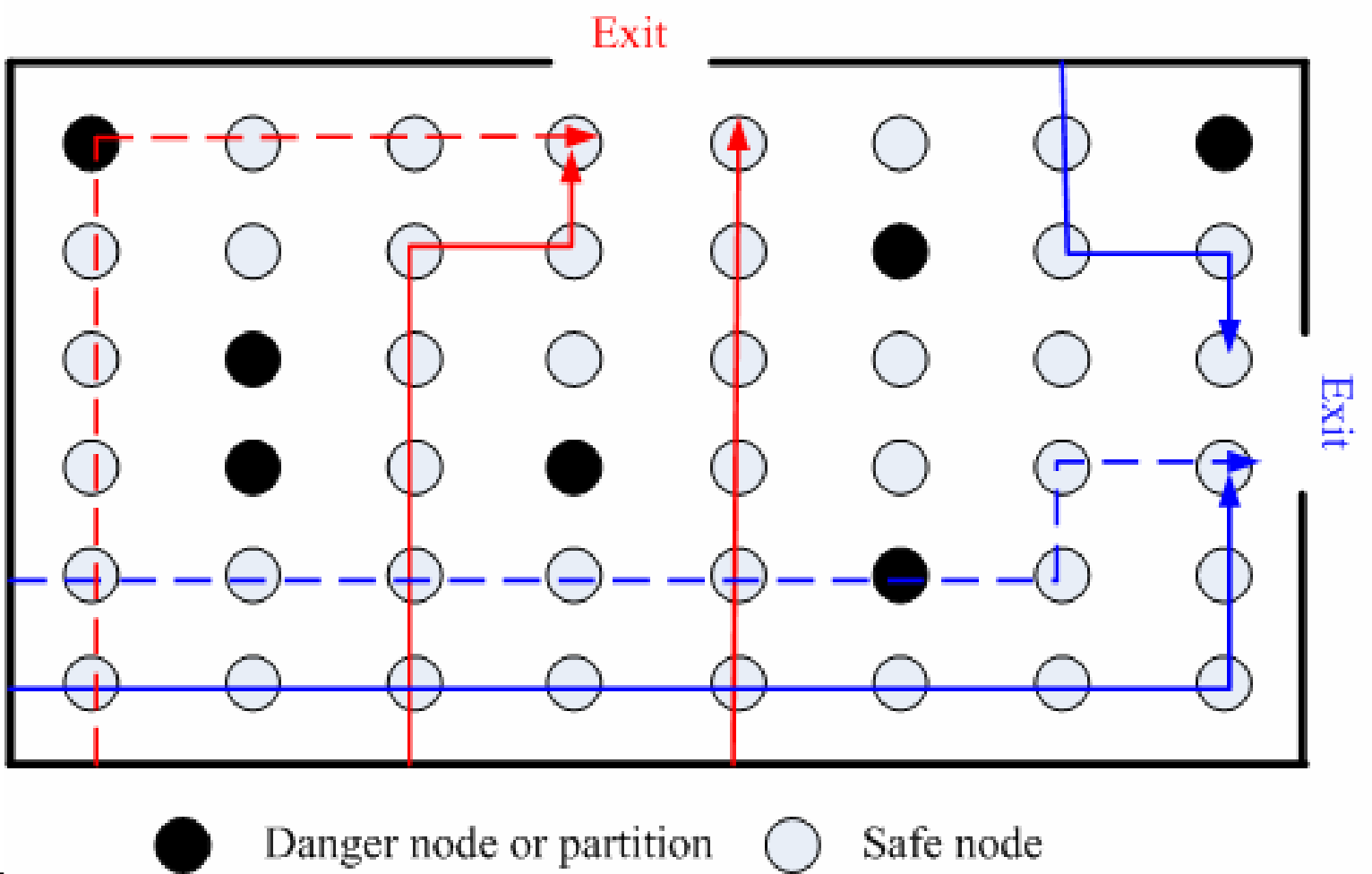
Emergency Guiding System

- How to find a safest way to exit the scene of a fire?
  - Pre-defined paths
  - Real-time paths
    - load balance
    - exposure

Emergency Guiding System



Pre-defined paths



Real-time paths