A Point-Distribution Index and Its Application to Sensor Grouping Problem

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Outline

- Introduction
- Normalized Minimum Distance
- Sensor Grouping Problem
- Maximizing- χ Node-Pruning (MMNP)
- Conclusions

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- **Introduction**
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Outlines of This Work

- Introduce a point-distribution index χ (normalized minimum distance)
- Demonstrate the resulting topology when χ is maximized
- Formulate a sensor-grouping problem
- Show the application of χ by employing it in a solution of the sensor-grouping problem
- Verify the effectiveness of this solution

Introduction of WSNs

- Features of Wireless Sensor Networks (WSNs)
  - Sensor nodes are low-cost devices
  - WSNs work in adverse environments
    - Fault Tolerance is very important
  - Sensor nodes are battery-powered
    - Prolonging network lifetime is a critical research issue

Introduction of WSNs

- Fault Tolerance
  - WSNs contain a large number of sensor nodes
  - Only a small number of these nodes are enough to perform surveillance work
- Energy-Efficiency
  - Exploit the redundancy
    - Put those redundant nodes to sleep mode

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Normalized Minimum Distance

- Definition
  - Formula

$x_i \ (i = 1, \dots n)$ The coordinates of each point

$$\mu = \frac{(\sum_{i=1}^{n} \sum_{j=1, j \neq i}^{n} ||x_i - x_j||)}{n(n-1)}$$

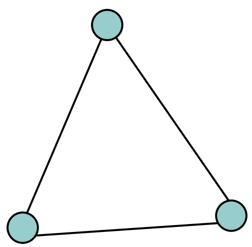
The average distance between each point-pair

$$\chi = \frac{\min(||x_i - x_j||)}{\mu} (\forall \ i, j = 1, 2, \dots, n; and \ i \neq j)$$

  - χ is the minimum distance between each pair of points normalized by the average distance between each pair of points
  - In interval [0, 1]

The Resulting Topology

- Maximizing χ
  - What is the resulting topology of points if χ is maximized?
  - If there are three points, when χ is maximized, these three points form an equilateral triangle.

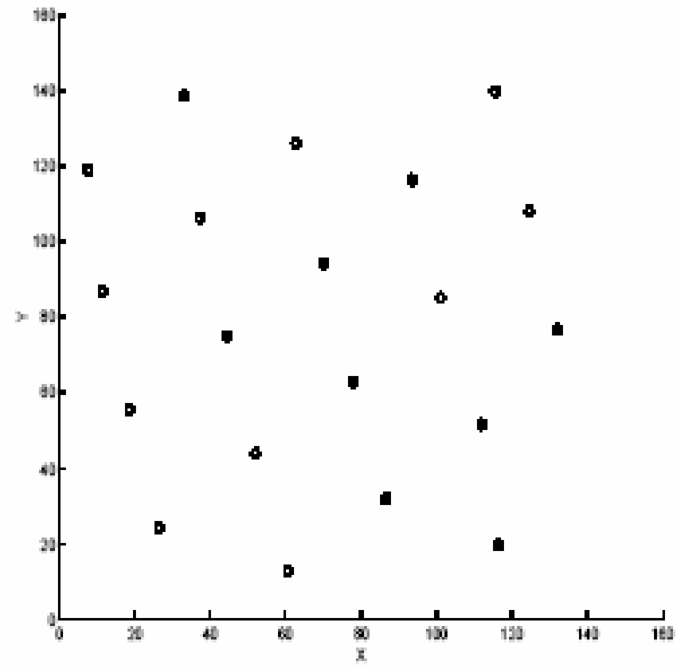


$\chi = 1$

  - What about other cases???

The Resulting Topology

- The resulting topology when χ is maximized



Node Number $= 20$, $\chi = 0.435376$

The Resulting Topology

- Vonoroi diagram formed by these points is a honeycomb-like structure
  - Wireless cellular network
  - Lowest redundancy
- Coverage-related problem
  - Maximizing χ is a promising approach to exploit redundancy
  - The effectiveness will be verified with a study of sensor-grouping problem

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Work/Sleep Scheduling

- Distributed Localized Algorithms
  - Each node finds out whether it can sleep (and how long it can sleep)
  - Much work is on this issue.
    - M. Cardei and J. Wu, “Coverage in wireless sensor networks,” in *Handbook of Sensor Networks*, (eds. M. Ilyas and I. Magboub), CRC Press, 2004.
    - SSCP by Xinyu (in his PhD thesis)

Work/Sleep Scheduling

- Sensor-Grouping Problem
  - Divide the sensors into disjoint subsets
    - Each subset can provide surveillance work
    - Schedule subsets so that they work successively
- Centralized algorithms
- Distributed grouping algorithms
  - MMNP: Maximizing-χ node-pruning algorithm
    - Locally maximize χ of sub-networks
  - ICQA: Incremental coverage quality algorithm
    - A greedy algorithm
    - A benchmark we design to verify the performance of MMNP

Sensor Grouping Problem

- Sensing Model
  - Event-detection probability by a sensor

$$\mathcal{P}(L, k_j) = \gamma \mathcal{E}(d) = \frac{\delta}{(\|\mathcal{L}(k_j) - L\|/\epsilon + 1)^{\beta}}$$

  - Cumulative event-detection probability

$$\mathcal{P}'(L) = 1 - \prod_{j=1}^{i} (1 - \mathcal{P}(L, k_j))$$

  - Coverage quality

$$\begin{aligned} \mathcal{C}(L) &= \mathcal{P}'(L) \\ &= 1 - \prod_{j=1}^{i} [1 - \frac{\delta}{(\|\mathcal{L}(k_j) - L\|/\epsilon + 1)^{\beta}}] > s. \end{aligned}$$

Covered

Sensor Grouping Problem

- Design a distributed algorithm to divide sensors into as many groups as possible, such that each group can ensure the coverage quality in the network area.
  - Requirement: the coverage quality of each location is larger than a threshold
  - Goal: the more groups, the better.
    - Because groups work successively, finding more groups means achieving higher network lifetime

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Maximizing- χ Node-Pruning

- A node *i* locally maximizes χ of the sub-network
  - Sub-network: node *I* and all its ungrouped sensing neighbors
  - Node-Pruning Procedure

    The candidate to be pruned satisfies that:

    - It is an ungrouped node.
    - The pruning of the node will not results in uncovered-points inside the sensing area of i.

    A candidate is pruned if the pruning of the candidate results in largest χ of the sub-network compared to the pruning of other candidates.
  - The node-pruning procedure continues and ungrouped sensing neighbors are deleted one by one until no node can be pruned

Maximizing- χ Node-Pruning

- Randomly pick up an ungrouped node and let it start the above procedure.
- When it stops, the node informs all the un-pruned ungrouped sensing neighbor they are in this group.
- The node then hands over the procedure to a newly selected node which is farthest from it.
- This hand-over procedure stops when a node finds that there is no newly selected node.
- The a new group is found.
- Continue this process until a node finds that the coverage quality of its sensing area cannot be ensured even if all the ungrouped sensing neighbors are working cooperatively with it.

Incremental Coverage Quality Algorithm

- Node selecting process: A node selects its ungrouped sensing neighbors into its group one by one

  - The selected neighbor is responsible to provide surveillance work for some *uncovered* parts of node i's sensing area, *i.e.*, the coverage quality of the parts, if this neighbor is not selected, does not fulfill the coverage quality requirement.
  - The selected neighbor results in highest improvement of the coverage quality of the neighbor's sensing area.

- This process stops when the coverage quality of the node's sensing area is entirely higher than required

Incremental Coverage Quality Algorithm

---Similar to MMNP---

- Randomly pick up an ungrouped node and let it start the above procedure. It informs a newly selected neighbor that the neighbor is in this group.
- When the procedure stops, the node then hand over the procedure to a newly selected node which is farthest from it.
- This hand-over procedure stops when a node finds that there is no newly selected node.
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Simulations

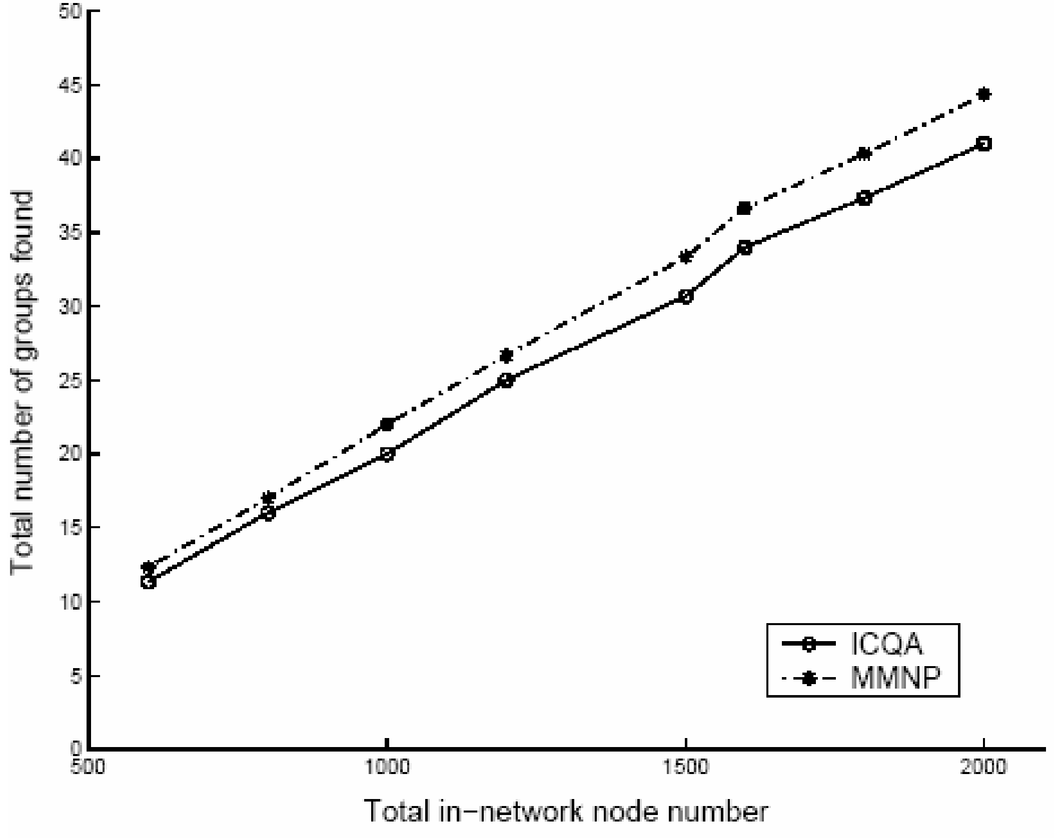
TABLE I

THE SETTINGS OF THE SIMULATION NETWORKS

Area of sensor field	400m*400m
ρ	20m
R	80m
α, β, γ and ϵ	1.0, 2.0, 1.0 and 100.0
s	0.6

The Number of Groups Found

- Randomly place 600, 800, …, 2000 nodes. Let the network performs MMNP and ICQA. Compare the resulting group-number.



The number of groups found by MMNP and ICQA

χ of the Resulting Groups

THE GROUPING RESULTS OF FIVE NETWORKS WITH $n = 1500$

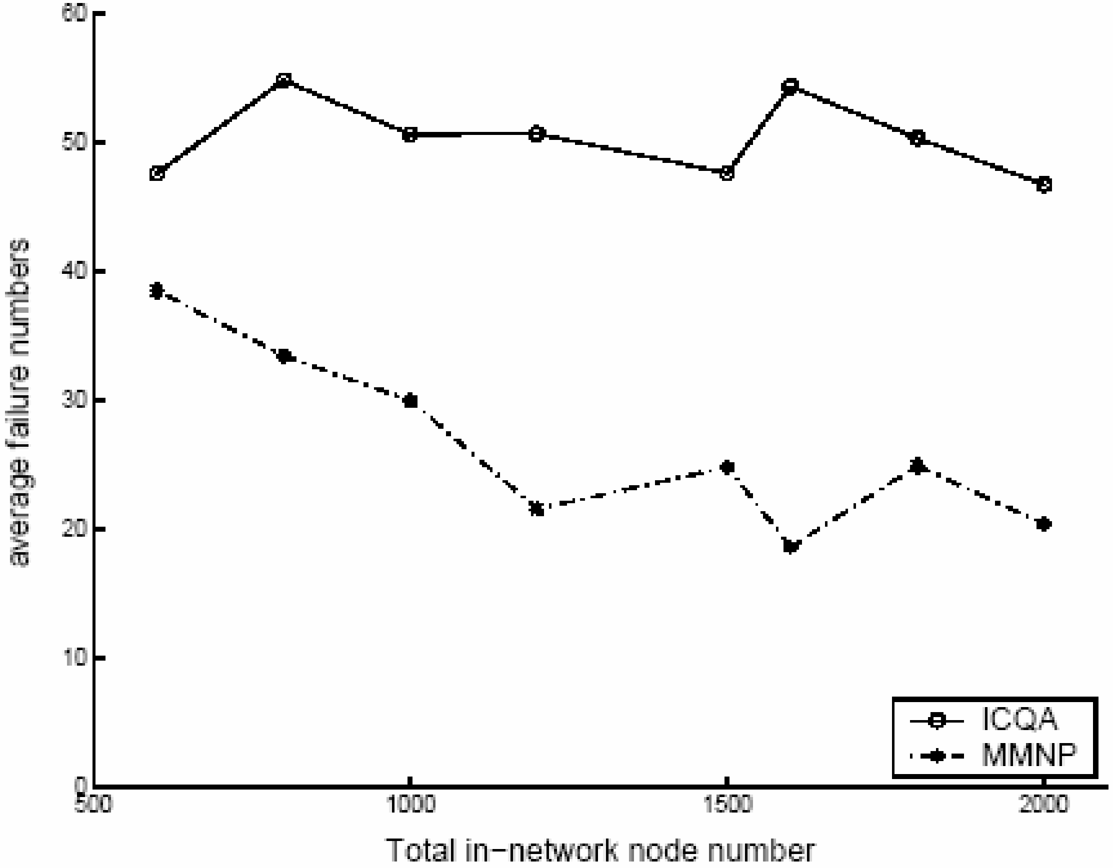
Net	MMNP Group Number	ICQA Group Number	MMNP Average χ	ICQA Average χ
1	34	31	0.145514	0.031702
2	33	30	0.145036	0.036649
3	33	31	0.156483	0.033578
4	32	31	0.152671	0.029030
5	33	32	0.146560	0.033109

The Number of Groups Found

- Conclusion: MMNP always outperforms ICQA in terms of number of groups found
  - MMNP can achieve long network lifetime.
  - Locally maximizing χ is a good approach to exploit redundancy.

The Performance of the Groups

- For each group found by MMNP and ICQA, let 10000 event happen at a random location. Compare the number of events where the coverage quality is below the required value



The failure numbers of MMNP and ICQA

The Performance of the Groups

- Conclusion: MMNP always outperforms ICQA in terms of the performance of the groups found
  - An idea, *i.e.*, MMNP, based on locally maximizing χ performs very well.
  - It further demonstrates the effectiveness of introducing χ in the sensor-group problem.

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Conclusion

- We propose a novel point-distribution index χ (normalized minimum distance)
- We demonstrate the effectiveness of introducing χ in coverage-related problem with a solution called MMNP for the sensor-group problem.

Q & A

Happy Lunar New Year

Thank You