GS^3: scalable self-configuration and self-healing in wireless sensor networks

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Presented by

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Outlines

- Introduction
- System model and problem statement
- Static network
- Dynamic network
- Mobile dynamic network
- Conclusion

Introduction (General)

- Geographic aware wireless sensor network.
- Dividing sensor nodes into a group of clusters (hexagonal cells – no overlap), each cluster consists of a head, each head forms a graph with a root connects to the external network.
- Considering the cluster radius

Introduction (General)

- The effect on the efficiency of local coordination such as data aggregation and load balancing.
- The effect on the degree of frequency reuse.
- The effect on scalability and availability (availability depends on the number of nodes in a cluster)

Introduction (Goals)

- Find a bound for cluster radius that reflects network intrinsic properties such as node distribution density.
- Develop self-configuration and self healing wireless sensor networks to withstand complex perturbations such as node join, leave, crash, and movement.
- Apply self-healing concept to general large scale networks

Introduction (Goals)

- Achieve scalability in three respects,
  - local knowledge enables each node to maintain the identities of only a constant number of nearby nodes.
  - local self-healing guarantees that all perturbations are confined to a tightly bounded region.
  - The process of self configuration and self healing require only local coordination.

System Model

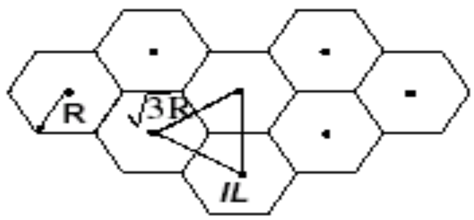
- A system consists of a set of nodes in a 2D plane.
- There are two kinds of nodes: big and small. The big node acts as the access point and external connection for small nodes.
- There are two types of perturbations: dynamic and mobile. Dynamic perturbation consists of node joins, leaves, deaths. Mobile perturbation consists of node movements.
- There are three types of networks: static, dynamic, and mobile dynamic networks.

Problem

- To design an algorithm such that R >= Rt (R is an ideal cell radius, Rt is called radius of tolerance – with high probability that there are multiple nodes in each circular area of radius Rt), constructs and maintains a set of cells and head graph that meet the following requirements,
  - Each cell is of radius R+-c (c is the deviation from an ideal radius R and is a function of node distribution.
  - Each node is in at most one cell.
  - A node is in a cell if there is a path to the big node.
  - The number of children for each node in the head graph is bounded.
  - The set of cells and the head graph are self-healing.

Static Network

- Consider only self-configuration algorithm since nodes are neither dynamic nor mobile.
- The concept is to divide the network into a set of hexagonal cells structure with the head located at the center of each hexagonal cell.



Static Network

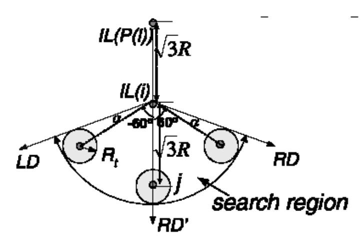
- In real environments, it may be impossible to divide the network into exact hexagons, and there may be no node located in an Ideal Location (IL), we can still approximate this structure by letting some node within Rt distance from IL be a head.
- Three steps solution
  - Locate the big node at the IL of some cell.
  - Each cell C then selects the closet node k to IL to be its cell head.
  - Every non-head small node j covered by a cell C becomes an associate.
  - ** the d band cells are a group of cells whose distance from the central cell is d ***

Static Network (Algorithm)

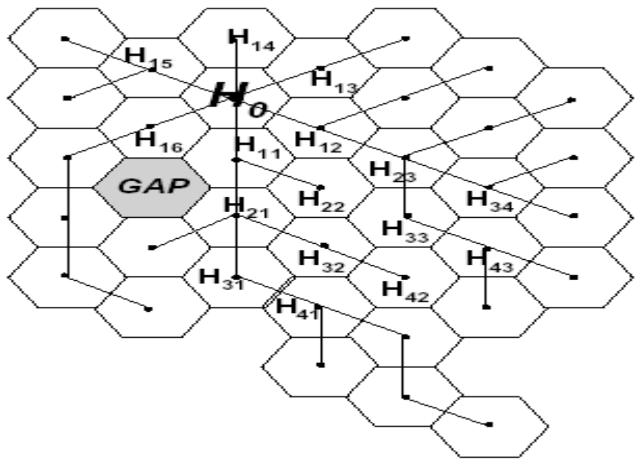
- The self-configuration algorithm consists of a one way diffusing computation across the network.
- The big node head selects the heads of its neighboring cells in its search regions. Then each newly selected head repeatedly selected the new heads and so on until no new head is selected.
- The big node head searches for new heads in all direction.

Static Network (Algorithm)

- For other nodes, calculate the ILs of neighboring heads NH in the LD and RD from the reference direction (RD' – can be any direction)
- For each IL that is not the IL of an existing head, selects the best node (in terms of the number of covered nodes) less than Rt away from the IL as a head.
- Any local information exchange is limited within $\sqrt{3}R + 2Rt$ distance between head to head, node to head.



Static Network (Result)



Static Network (Verification)

- Verification of the algorithm by using invariant and fixpoint.
- The main idea of invariant and fixpoint are to check that all nodes are connected to the root node (big node) and the resulted configuration obeys the hexagonal structure.
- The algorithm should reach coverage and connectivity requirements within a constant amount of time (function of the maximum Cartesian distance between the big node and any small node in the system).

Dynamic Network

- Handle node leave and death with three algorithms: head shift, cell shift, and cell abandonment.
- Self stabilization can handle other remaining perturbations, i.e., node joins and state corruptions.
- Head shift occurs when there is an unanticipated head node leave or death. New head can be found with high probability from a set of associates within Rt distance from the IL (candidates).

Dynamic Network

- Cell shift occurs when the set of candidates of a cell becomes empty due to energy exhaustion forcing the IL to change to another point IL'.
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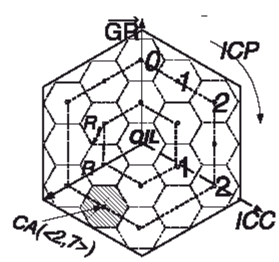
- Due to statically uniform energy dissipation across the network, the entire head graph as well as head level structure will slide as a whole but maintain consistent relative location among cells and heads.
- Cell abandonment occurs when the nodes in an area of a radius larger than Rt die at the same time. Every node in the problem cell becomes an associate of one of the neighboring cells.

Dynamic Network (Algorithm)

- In the head selection, if there is an Rt gap in cell C (no nodes within the Rt radius of the IL of a cell C), every node in C becomes an associate with its neighboring cells. By periodically checking presence of a node within the Rt radius of the IL, then the node becomes a new head for cell C.
- If there is no existing head within 3^0.5*R + 2*Rt, the new node joins the system by selecting the best associate as its surrogate head.
- In the event of head node fail, head shift enables the highest ranked candidate to become then new head of a cell.

Dynamic Network (Algorithm)

- Cell shift enables the cell head to strengthen its candidate set by selecting a better IL.
- OIL is the original IL.
- ICC is the Intra Cell Cycle index,
- ICP is the Intra Cycle Position index.
- A group of small hexagonal cells of the Rt radius are formed within the original cell. Each small cell IL is the candidate IL in the event of cell shift.



Dynamic Network (Algorithm)

- Cell abandonment enables nodes within a heavily perturbed cell to become an associate in one of its neighboring cells (back to state of boot up - join).
- A parent head and its children heads constantly monitor each other. If a neighboring head j is closer to H0 than its current parent, i sets j as its new parent.
- Each head synchronizes its IL with neighboring heads, child, and its parent.
- Sanity check is done periodically, each h checks the hexagonal relation with its neighbors, if head h fails, then it becomes an associate.

Dynamic Network (Deviation)

- Rt gap results in the existence of non-ideal cells that are not hexagonal.
- The radius of non-ideal cells C' depends on the diameter of the Rt-gap of the perturbed region.
- Let λ be the average number of nodes in a circular area of radius 1. Using Poisson distribution, the probability α that there is no node in an area of radius Rt is
- Following binomial distribution, the expected number of non-ideal cells Ge = $n\alpha$
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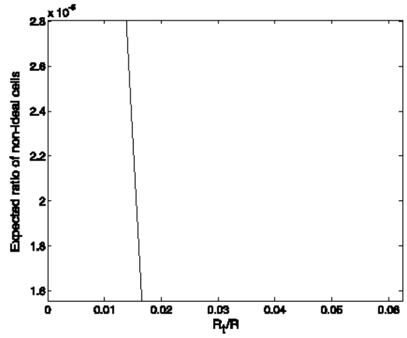
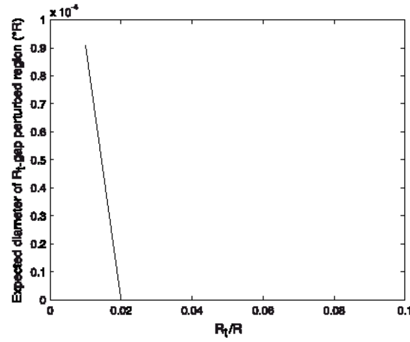
- The expected diameter of an Rt gap perturbed region is $\frac{2\alpha}{(1-\alpha)^2}R$

Dynamic Network (Deviation)





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Mobile Dynamic Network

- Node can move. The probability of movement is inversely proportional to the distance of movement.
- Node mobility is modeled as a correlated node join and leave.
- The path between H0 and every head is of minimum distance. If H0 moves more than Rt distance from its IL, the closest head to H0 will act as a proxy.
- The impact of H0 movement is contained within a radius $\sqrt{3}d/2$, where d is the distance H0 moves.

Conclusion

- GS3 is an algorithm for self-configuring and self-healing wireless sensor networks.
- The algorithm results in stable hexagonal cell configuration with low overlap.
- The algorithm enables the network to locally and effectively adapt to changes such as node join, leave, or death.
- The algorithm is applicable to both static and dynamic network and is scalable due to local knowledge, local self-healing, and local coordination properties.

Conclusion

- The algorithm is also applicable to the case where the ideal cell radius R is larger than the maximum transmission range of small nodes.
- The possible future work is to study in detail how to deal with different degrees of node dynamics and mobility.