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Wireless Sensor Network: Topology Issues

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Abstract

Wireless Sensor Networks are highly distributed self organized systems. WSN have been deployed in various fields. Now a day, Topology issues have received more and more attentions in Wireless Sensor Networks (WSN). While WSN applications are normally optimized by the given underlying network topology, another trend is to optimize WSN by means of topology control. In this area, a number of approaches have been invested, like network connectivity based topology control, cooperating schemes, topology directed routing, sensor coverage based topology control. Most of the schemes have proven to be able to provide a better network monitoring and communication performance with prolonged system lifetime. In this survey paper, I provide a full view of the studies in this area.

1. Introduction

Wireless Sensor Networks (WSNs) have become an emerging technology that has a wide range of potential applications including traffic control, object tracking, scientific observing and forecasting, and environment monitoring etc

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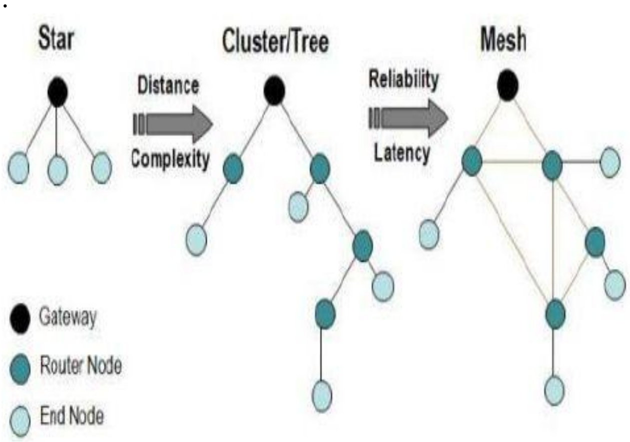

Figure1. WSN Topologies

A WSN normally consists of a large number of distributed nodes that organize themselves into a multi-hop wireless network and typically these nodes coordinate to perform a common task.

To achieve a lasting and scalable WSN design, the following aspects have to be carefully taken into account in the design stage:

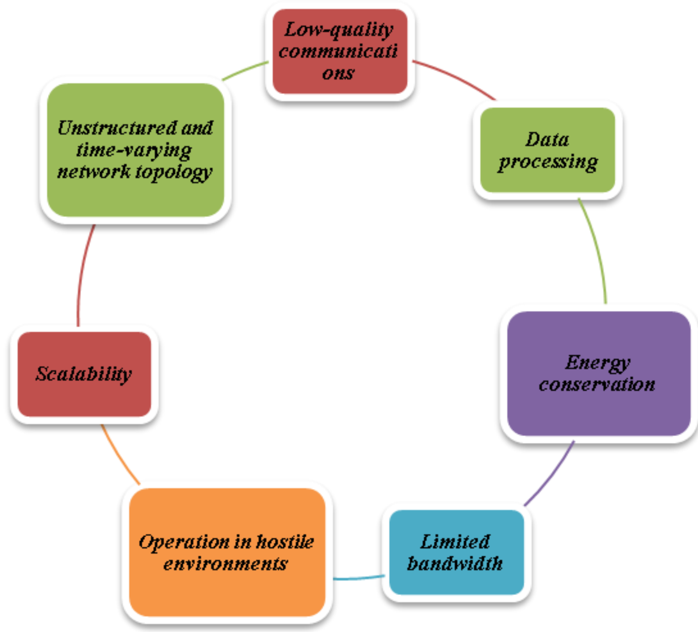

Figure1.2 Aspects need to be taken care of

2. Topology Issues, the Taxonomy

There are mainly two categories of topology issues.

(1)Topology Control Problems and,
(2)Topology Awareness Problems

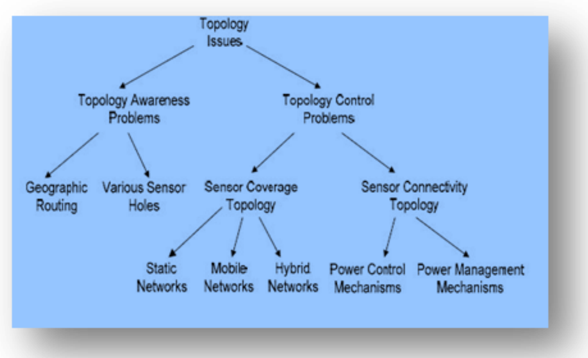

Figure2. A Taxonomy of topology issues in WSNs

2.1 Topology Control Problems

It can be further divided into two categories:

2.1.1 Sensor Coverage Topology

The coverage topology describes the topology of sensor coverage and is concerned about how to maximize a reliable sensing area while consuming less power. There are three categories into Sensor Coverage Topology: Static Network, Mobile Network and Hybrid Network.

Static Network:

For a static sensor network, proposed approaches have different coverage objectives. I introduce these approaches separately.

Partial Coverage:

WSN system functioning time by keeping only a necessary set of sensors working in case the node deployment density is much higher than necessary. PEAS protocol consists of two algorithms: Probing Environment and Adaptive Sleeping.

Single Coverage:

The Optimal Geographical Density Control (OGDC) protocol tries to minimize the overlap of sensing areas of all sensor nodes for cases when $Rc \geq 2Rs$ where Rc is the node communication range and Rs is the node sensing range. OGDC is a fully localized algorithm but the node location is needed as a pre-knowledge.

Multiple coverage:

A distributed density control algorithm based on time synchronization among the neighbors. A node can decide its on-duty time such that the whole grid still gets the required degree of coverage.

Mobile Network:

The deployment schemes for movable sensors. Given an area to be monitored, the proposed distributed self-deployment protocols first discover the existence of coverage holes in the target area then calculate the target positions and move sensors to diminish the coverage holes. The sensor network in the viewpoint of virtual forces, nodes only use their sensed information to make moving decisions. It is a cost effective and no communication among the nodes or localization information is needed. For the DSS (Distributed Self-Spreading) algorithm proposed, sensors are randomly deployed initially. They start moving based on partial forces exerted by the neighbors. The forces exerted on each node by its neighbors depend on the local density of deployment and on the distance between the node and the neighbor.

Hybrid Network:

The coverage scenario with only some of the sensors are capable of moving has been under active research, especially in the field of robotics for exploration purpose. The movement capable sensors can help in deployment and network repair by moving to appropriate locations within the field to achieve desired level of coverage. Combined solution for the exploration and coverage of a given target area. The coverage problem is solved with the help of a constantly moving robot in a given target area. The algorithm does not consider the communications between the deployed nodes. All decisions are made by the robot by directly communicating with a neighbor sensor node. Single coverage problem by moving the available mobile sensors in a hybrid network to heal coverage holes

2.1.2 Sensor Connectivity Topology

The connectivity topology on the other hand is more concern more about network connectivity and emphasizes the message retrieve and delivery in the network. Two kinds of mechanisms have been utilized to maintain an efficient sensor connectivity topology:

Category	*Approach*	*Characteristics*
Static Network	Partial Coverage	Distributed sleeping schedule
		Distributed sleeping schedule, guarantee finite delay bound
	Single Coverage	Residual energy consideration
		Sector based coverage calculations
		Uniform disk sensing model
	Multiple Coverage	Configurable degree of coverage.
		Non-unit disk model supported
		Grid based differentiated degree of coverage
Mobile Networks	Computational Geometry	Localized, Scalable, Distributed.
		Single coverage based. Residual energy considerations.
	Virtual Forces	Scalable, Distributed. No local communication required.
		Scalable, Distributed. Residual energy based.
Hybrid Networks	Single Mobile sensor	Distributed. No multi-hop communications.
	Multiple Mobile Sensor	Voronoi diagram is used for single coverage requirement.

Power Control Mechanisms:

The goal of power control mechanisms is to dynamically change the nodes' transmitting range in order to maintain some property of the communication graph, while reducing the energy consumed by node transceivers because they are one of the primary sources of energy consumption in WSNs. Power control mechanisms are fundamental to achieving a good network energy efficiency. Power control is studied in homogeneous and non-homogeneous scenarios which can be distinguished by examine if the nodes have the same transmitting range or not. For homogeneous network, the CTR (Critical Transmitting Range) problem has been investigated in theoretical ways as well as practical viewpoints. A distributed protocol, called COM-

POW that attempts to determine the minimum common transmitting range needed to ensure network connectivity. They show that setting the transmitting range to this value has the beneficial effects of maximizing network capacity, reducing the contention to access the wireless channel, and minimizing energy consumption. the tradeoff between the transmitting range and the size of the largest connected component in the communication graph. The experimental results presented show that, in sparse two and three-dimensional networks, the transmitting range can be reduced significantly if weaker requirements on connectivity are acceptable: halving the critical transmitting range, the largest connected component has an average size of approximately 0.9*n*. This means that a considerable amount of energy is spent to connect relatively few nodes. Non-homogeneous networks are more challenging because nodes are allowed to have different transmitting ranges. The problem of assigning a transmitting range to nodes in such a way that the resulting communication graph is strongly connected and the energy cost is minimum is called the Rang Assignment (RA) problem. It is shown to be NP-hard in the case of 2D and 3D networks. However the optimal solution can be approximated within a factor of 2 using the range assignment generated. An important variant of RA has been recently studied is based on the concept of symmetry of the communication graph. Due to the high overhead needed to handle unidirectional links in routing protocols or MAC protocols which are naturally designed to work under the symmetric assumption, Symmetric Range Assignment (SRA) shows more practical significance. However, SRA remains NP-hard in 2D and 3D networks, and it even incurs a considerable additional energy cost over RA. I can refine SRA to WSRA (Weakly Symmetric Range Assignment) which weakens the requirement that the communication graph contains only bidirectional links by allowing the existence of the unidirectional links but requiring the symmetric sub graph of the communication graph resulting from RA connected. In the released WSRA problem, only marginal effect on the energy cost has been induced while the desired symmetry property has been kept.

Power Management Mechanisms:

Power management is concerned of which set of nodes should be turned on/off and when, for the purpose of constructing energy saving topology to prolong the network lifetime. It can utilize information available from all the layers in the protocol stack. In GAF approach, nodes use location information to divide the field into fixed square grids. The size of each grid stays constant, regardless of node density. Nodes within a grid switch between sleeping and listening mode, with the guarantee that one node in each grid stays up so that a dynamic routing backbone is maintained to forward packets. Span, a power saving topology maintenance algorithm for multi-hop ad hoc wireless networks which adaptively elects coordinators from all nodes to form a routing backbone and turn off other nodes' radio receivers most of the time to conserve power. STEM approach, which exploits the time dimension rather than the node density dimension to control a power saving topology of active nodes. They switch nodes between two states, "transfer state" and "monitoring state". Data are only forwarded in the transfer state. In the monitoring state, nodes remain their radio off and will switch into transfer state to be an initiator node on event detected. The extended study on combining STEM and GAF shows the potential of further power saving by exploiting both time dimension and node density dimension.

2.2 Topology Awareness Problems

It includes geographic routing problems and sensor holes problems.
Geographic routing uses geographic and topological information of the network to achieve optimal routing schemes with high routing efficiency and low power consumption.
Various sensor holes, such as Jamming holes, sink/black holes and worm holes, may form in a WSN and create network topology variations which trouble the upper layer applications. For examples, intense communication may cause jamming holes which will fail to deliver message to exterior nodes. Sink/Black holes and worm holes are caused by nodes exhausted around sink node or pretended sinks or by malicious nodes. If sensor holes issues are not treated carefully, they will create costly routing table and exhaust the intermediate nodes rapidly.

Geographic Routing:

Geographic routing approach relies on greedy forwarding to route packets based on nodes' local information on the network topology. The protocol starts in greedy forwarding mode, and assumes the location information of sensor nodes can be obtained by supporting systems. GPSR recovers from local maximum position by using perimeter rouging mode and the right-hand rule. kis et al. propose the Compass Routing algorithm and FACE-1 algorithms that guarantees the destination is reached even when local minimum phenomenon occurs in greedy forwarding. Similar to the work in, Bose et al. propose the FACE-2 routing algorithm. In contrast to GPSR, routing in FACE-2 is done through the perimeter of the Gabriel Graph (CG) formed at each node. It also modifies the FACE-1 so that the perimeter traversal follows the next edge whenever that edge crosses the line from the source to destination. Obviously, the downside of FACE-2 is that it consumes more energy in the perimeter nodes.

Hole Problems:

For most of the geographic routing schemes, a routing hole consists of a region in the sensor network, where either node are not available or the available nodes cannot participate in the actual routing of the data due to various possible reasons. In order to prevent the infection to the packet delivery by sensor holes, the geographic routing schemes do not provide methods to detect and localize the holes. Theoretical work on determining sensor holes in which so-called *stuck node* is defined and an algorithm called *BOUNDHOLE* is proposed to find the holes utilizing the strong stuck nodes. Study an application specific scenario for the underground monitoring in coal mine. They propose a topology maintenance protocol SASA, which claims to rapidly detect the structure variation during underground collapse by regulating the mesh sensor network deployment and formulating a collaborating mechanism based on the regular beacon strategy for sensors. The so-called *edge nodes* outline the sensor hole and report it to the sink. To the best of our knowledge, the SASA protocol is the first work which relates the topology variation to the actual geographical changes. Wood et al. discuss jamming hole in. The resilience of various routing protocols and energy conserving topology maintenance algorithms against sink holes. They showed that popular routing protocols like directed diffusion, rumor routing and multi-path variant of directed diffusion etc. are all vulnerable to sink holes attacks. For geographical greedy forwarding algorithms it is more difficult to create sink holes because in this case a malicious node has to advertise different attractive locations to different neighbors in order to qualify as next hop.

3. Conclusions

Two major issues found in topology in WSNs, namely topology awareness and topology control. Topology awareness problems construct applications or upper protocols to conform the underlying topology. Typical approaches applied in this category do not actively consider improving the topology itself for the specific applications. Topology control mechanisms focus more on constructing an energy-efficient and reliable network topology and normally do not touch individual applications.

Power control and power management are two different types of topology controlling methods. By focusing on integrating power control and power management, it is possible to provide noticeable improvements on network topology and efficiencies of energy usage.

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