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An Analysis of Energy Efficient Collector Techniques in Wireless Sensor Networks

Dr. V. Umadevi[1], S. Sharmila[2]
[1]Research Guide, Department of Computer Science, Jairams Arts & Science College, Attamparappu, Kakkavadi(PO), Karur, Tamilnadu, India-639003
[2]MPhil Scholar, Department of Computer Science, Jairams Arts & Science College, Attamparappu, Kakkavadi(PO), Karur, Tamilnadu, India-639003

***Abstract*— *Recent advances in environmental energy harvesting technologies have provided great potentials for traditional battery-powered sensor networks to achieve perpetual operations. Due to dynamics from the temporal profiles of ambient energy sources, most of the studies so far have focused on designing and optimizing energy management schemes on single sensor node, Efficient use of the limited energy resources of wireless sensor network (WSN) nodes is critically important to support these advances, and application of topology control methods will have a profound impact on energy efficiency and hence battery lifetime. We focus on the energy efficiency issue and present a comprehensive study of topology control techniques for extending the lifetime of battery powered WSNs. First, we review the significant topology control algorithms to provide insights into how energy efficiency is achieved by design. Further, these algorithms are classified according to the energy conservation approach they adopt, and evaluated by the trade-offs they offer to aid designers in selecting a technique that best suits their applications. Since the concept of "network lifetime" is widely used for assessing the algorithms' performance, we highlight various definitions of the term and discuss their merits and drawbacks*.

***Keywords*— *Wireless sensor network, topology control, energy efficiency, topology control algorithms, network lifetime*.

I. INTRODUCTION

WSNs are presumed to be deployed using battery-powered stationary sensor nodes equipped with sensing, computing and wireless communicating modules. In a broad range of potential applications, inexpensive sensors can be embedded into buildings or scattered into spaces to collect, process, store and send out relevant information for various civilian or military purposes. There have been two different approaches to maximizing network lifetime. One indirect approach aims to minimize energy consumption, while the other approach directly aims to maximize network lifetime. Although these efforts help extend network lifetime, they do not address precisely the problem of maximizing network lifetime [1], [2].

A wireless sensor network consists of a large number of tiny sensing devices, deployed in a region of interest. Each device has processing and wireless communication capabilities, which enable it to gather information from the environment and to generate and deliver report messages to the remote base station (or sink node). The base station aggregates and analyzes the report messages received and decides whether there is an unusual or concerned event occurrence in the area of interest [3], [4].

WSNs are also different from other networks in the following aspects: they are densely deployed, nodes are susceptible to failure, and heavily rely on broadcast communications. Their topology is dynamic, in which node-to-node links are established and broken quite often due to various reasons, including deliberate changes to the transmission power of the nodes, node failure or mobility. In summary, maintaining a fully connected topology for such networks is a challenge and requires careful application of topology control. Nowadays, applications of very large scale WSNs are becoming a reality. Examples are being the Smart Grid [5], The Internet of Things [6], Machine-to-Machine (M2M) communications networks [7], and smart environments [8].

II. WSN TOPOLOGY CONTROL

In WSNs, a topology provides information about a set of nodes and connectivity (links) between a pair of nodes in the set. To construct a network topology, each sensor node discovers its neighbors and relative links using its maximum transmission power. This approach created high dense and sparse. To avoid this problem, a proper topology control should be employed to eliminate the unnecessary links in the dense network without sacrificing the network performance. [9].

We define topology control as a technique that uses any controlled network parameter to generate and maintain a topology for the benefits of reducing energy consumption and achieving a desired property for an entire network. The possible controlled parameters that can be modified to gain a desired topology are transmission power, modes of nodes and role of nodes. Our definition differs from other topology control definitions that are conventionally adopted in the topology control field in the following respects. For example, many authors [10], consider topology control as a technique whereby nodes dynamically change their transmission range to gain energy saving and/or improve throughput.

Another definition for topology control used by other authors is power control. Although this technique involves controlling the nodes' transmission power, it does not aim to achieve the energy efficiency of an entire network. Paolo [11] describes power control as a technique in which nodes adjust the transmit power to achieve a node wide perspective such as energy efficient algorithms of the wireless transceiver. Another example of power control mentioned in is the technique that aims to select the best transmit power level for a single wireless transmission, possibly involving several hops.

III. Power Adjustment Approach

The power adjustment approach allows nodes to vary their transmission power to reduce energy incurred in transmission. Rather than transmitting at maximum transmission power, nodes work in a collaborative manner to adjust and find the appropriate transmission power to form a connected network. We mentioned three power adjustment algorithms in the following sections:

1. Minimum Energy Communication Network (MECN)
2. Small Minimum Energy Communication Network (SMECN)
3. COMPOW

IV. Power Mode Approach

The power mode approach is the technique that exploits the feature of the operating mode available in the network interface of sensor nodes to gain energy saving. There are four operating modes of the nodes: sleep, idle, transmit and receive modes. The energy consumed during the transmit and receive modes is generally higher than that in the sleep mode.

In order to transmit or receive packets, nodes must transit to idle mode. However, continuous listening of incoming packets that are not addressed to the idle nodes can contribute to high energy dissipation that is quite significant compared to those in sleep mode. This suggests that the redundant nodes sitting in idle can be switched to energy saving mode by placing them in the sleep mode. This feature has been used in topology control to optimize the energy and prolong the network lifetime without sacrificing the network capacity and connectivity. In this section, a discussion on three power mode algorithms that deal with powering-off idle nodes as well as coordinating the sleep and wake-up scheduling of the nodes is presented.

1) Geographical Adaptive Fidelity (GAF)
2) Sparse Topology and Energy Management (STEM)
3) Adaptive Self-Configuring Sensor Network Topologies (ASCENT)

V. Clustering Approach

The idea of clustering is to select a set of nodes in the network to construct an efficient topology. The selection of neighbors can be made on various criteria namely, energy reserve, density of the network or node identifier. Unlike in power adjustment or power mode approaches, the clustering approach constructs a topology with hierarchical structures that are scalable and simple to manage. The advantage of clustering is that a certain task can be restricted to a set of nodes called cluster heads and they can be assigned for collecting, processing and forwarding packets from non-cluster heads. This mechanism provides an efficient network organization. Other attractive features of the clustering approaches include the load balancing and data aggregation or data compression offered for prolonged network lifetime. In some clustering approaches, the selection of the clusterheads remains fixed. Hence, clusterheads typically experience faster energy depletion because they are heavily loaded with various tasks. This problem is overcome by randomizing the selection of clusterheads to distribute loads fairly among nodes in the network.

1) Power Aware Connected Dominating Set (PACDS)
2) Energy Efficient Distributed Connecting Dominating
3) Sets (ECDS)
4) Topology Management by Priority Ordering (TMPO)

VI. Hybrid Approach

The hybrid approach is a topology control technique that uses some form of clustering in combination with other approaches such as power adjustment or power mode to achieve additional energy saving. The following section presents three such hybrid algorithms that aim to conserve energy.

1) SPAN
2) CLUSTERPOW
3) Low-Energy Adaptive Clustering Hierarchy (LEACH)

VII. Comparative Analysis

Category	Algorithm	Advantages	Disadvantages
Power Adjustment	MECN	Strong Connectivity	Needs location information(GPS) to build system topology
	SMECN	Strong Connectivity. More power and time efficient than MECN	Needs location information(GPS) to build topology
	COMPOW	Practical-based topology control. Built on wireless testbed	High message overhead for computing multiple power levels
Power Mode	GAF	Low Communication overhead	Relies on location information system to compute the grid and allocate nodes into the grid
	STEM	Energy efficient for event-triggered application	Trade-off energy savings with setup latency
	ASCENT	Self-reconfigurable and adaptive to react to applications dynamic events	Possibly fast energy depletion among nodes due to uneven load distribution
Clustering	PACDS	Simple and quick to calculate the connected dominating set and location service-free	Not suitable for high mobility
	ECDS	Nodes energy residual considered in the construction of connected domain set	High message overhead
	TMPO	Stable topology and load balancing features. Appropriate for	High message overhead and computationally intensive

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		high mobility networks.	
Hybrid	SPAN	location service-free and exploits the advantage of power saving 802.11 for routing	Nodes have to periodically wake up and listen for traffic advertisements
	CLUSTERPOW	Easy maintenance of clusters and possible implementation on wireless card	Significant message overhead for computing multiple power levels
	LEACH	Offers a variety energy efficient mechanisms	Complicated tasks performed by cluster heads and not scalable

VIII. CONCLUSION

In WSNs, nodes operate with a limited battery source and they cease operating once their battery depletes. Therefore, a network's lifetime is strongly dependent on battery lifetime. It is for this reason that power conservation and power management become the main focus in the design of topology control algorithms. A common approach to address the power issue is to develop energy efficient algorithms that optimize the use of the energy supply. Although considerable research effort has been devoted to topology control problems, there are many issues that are yet to be addressed. Based on the outcomes of our work, we derive and list the potential open issues that need further investigation.

The future topology control techniques should explore the hybrid approach to develop a simple and energy efficient topology control solution. By integrating the power mode, power adjustment and clustering approaches, we can exploit the advantages of each approach. For instance, the techniques that combine clustering and power adjustment can utilize the advantage of the clustering approach to simplify the network and use the ability of the power adjustment to solve the optimal transmission power. The clustering approach can also be used with the power mode approach to reduce the energy consumption spent in idle mode. The power adjustment and power mode approaches can be jointly adopted to find the optimal transmission range for each node. In addition, the radio of the redundant nodes can be switched-off to gain more power saving. To the best of our knowledge, none of the existing topology control algorithms integrates power adjustment, power mode and clustering approaches.

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