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Distributed topology control algorithm on broadcasting in wireless sensor network

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ABSTRACT

Topology control can enhance energy efficiency and prolong network lifetime for wireless sensor networks. Several studies that attempted to solve the topology control problem focused only on topology construction or maintenance. This work designs a novel distributed and reliable energy-efficient topology control (RETC) algorithm for topology construction and maintenance in real application environments. Particularly, many intermittent links and accidents may result in packet loss. A reliable topology can ensure connectivity and energy efficiency, prolonging network lifetime. Thus, in the topology construction phase, a reliable topology is generated to increase network reachable probability. In the topology maintenance phase, this work applies a novel dynamic topology maintenance scheme to balance energy consumption using a multi-level energy threshold. This topology maintenance scheme can trigger the topology construction algorithm to build a new network topology with high reachable probability when needed. Experimental results demonstrate the superiority of the RETC algorithm in terms of average energy consumption and network lifetime.

1. Introduction

Wireless sensor networks (WSNs) (Wang and Liu, 2011) are a very popular technology for monitoring and acting upon events in dangerous or risky locations. These WSNs usually have resource constraints, such as limited power, limited computational capacity, and limited bandwidth. Thus, energy-efficient algorithms can prolong the lifetime of WSNs. Topology control is an effective method for improving the energy efficiency of WSNs (Poduri et al., 2009). This work defines topology control as an iterative process (Fig. 1) (Labrador and Wightman, 2009). Topology control has three phases: sensor deployment, topology construction, and topology maintenance. First, the sensor deployment phase is common to all WSN applications. After this initialization phase, the second phase is to build a new topology, called the topology construction phase. In this phase, a new topology is established while maintaining connectivity. The main goal of the topology construction phase is to build a topology that saves energy and preserves high network reachable probability. As soon as the topology construction phase establishes this topology, the topology maintenance phase must start. During this phase, nodes monitor topology status and trigger a new topology construction phase when appropriate. Over a network's lifetime, this cycle typically repeats many times until node energy is depleted.

Since wireless links are inherently unreliable, packet losses are not acceptable for many mission-critical applications that require topology control to provide a certain level of reliability. The proposed topology control algorithm, the reliable energy-efficient topology control (RETC) algorithm, provides highly reliable and energy efficient network. In traditional networks, the network model is based on the free-space propagation model (Santi, 2005). However, this model is not practical in real application environments due to the *transitional region phenomenon* (Woo et al., 2003). Particularly, a link, called an intermittent link or lossy link, is reachable but not always connected. That nodes in a WSN are connected to their neighbors with a certain packet loss probability is generally assumed. Thus, reliability should be achieved while keeping algorithm design in mind. A reliable topology can achieve connectivity and energy efficiency, prolonging network lifetime. This work models the reliability issue as a reachable probability problem for a network. Additionally, considering only topology construction is not sufficient to achieve an energy-efficient topology control algorithm. This work designs a dynamic topology maintenance scheme in the topology control algorithm. In the topology maintenance phase, nodes monitor topology status and trigger topology construction when appropriate to increase network lifetime. Thus,

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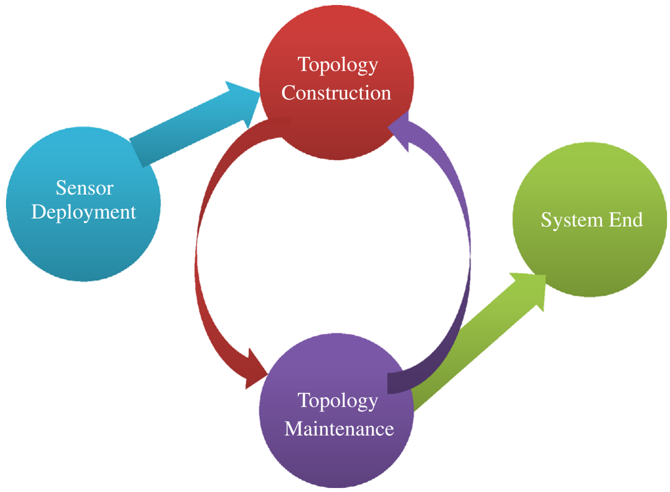

Fig. 1. The topology control cycle.

this phase can balance the energy consumed by nodes to prolong network lifetime. This work proposes a distributed algorithm that enables nodes to autonomously create and maintain energy-efficient links with reliability. The protocol defines proximity metrics to ensure that a network is reliable and energy efficient to extend its lifetime.

The remainder of this paper is organized as follows. Section 2 reviews relevant literature. Section 3 elucidates the proposed topology control algorithm. Section 4 summarizes simulation results. Section 5 draws conclusions.

2. Related work

A WSN is usually composed by a large number of nodes. Each node has a processing unit, a radio transceiver, sensor units, and a power unit usually equipped with a low-capacity battery (Raghunathan et al., 2002). Due to its limited power resources, and because batteries cannot be replaced easily, a power-saving algorithm is needed. Therefore, an energy-efficient topology control mechanism is needed to extend system lifetime (Ren and Meng, 2009; Moraes et al., 2009).

Sensor deployment in WSNs has attracted considerable attention recently (Baumgartner et al., 2009). Most studies formulated the deployment problem as a coverage problem or connectivity problem (Zhu et al., 2012). The design goal of WSN deployment is to cover the monitored area with the fewest sensors while meeting system requirements. To maximize sensor coverage and ensure network connectivity, Tan et al. (2009) developed a novel deployment scheme. That scheme is adaptable to arbitrary network densities or communication ranges, as well as to obstacles. Another study (Wang et al., 2008) developed an analytical framework for the coverage and lifetime of a WSN that follows a 2D Gaussian distribution. A Gaussian distribution is a highly effective deployment strategy in WSNs applications; the Gaussian distribution can increase network lifetime substantially. In the authors' previous work (Shiu et al., 2011), a divide-and-conquer deployment algorithm based on triangles was developed to evaluate the number of sensors and *x*–*y* coordinates of all sensors that are deployed in a hole.

Topology construction should be triggered after the sensor deployment phase. A distributed energy-efficient topology control (DETC) algorithm for home machine-to-machine (M2M) networks was previously developed by the authors' (Lee and Yang, 2012). The M2M network needs various sensor types to meet application requirements. The DETC algorithm can perform only in home M2M networks. In this scheme, nodes create and maintain energy-efficient links autonomously and achieve the objective of prolonged lifetime with reduced energy cost. Ding et al. (2009) applied an adaptive partitioning scheme for node scheduling and topology control in sensor networks with the aim of reducing energy consumption. The connectivity-based partition approach (CPA) divides nodes based on their measured connectivity instead of guessing connectivity based on their positions. This approach guarantees connectivity for the backbone network. To reduce power consumption, Ma et al. (2007) constructed network topologies with a small number of coordinators while maintaining network connectivity. By reducing the number of coordinators, average duty cycle is reduced and battery life is extended. Sethu and Gerety (2010) developed the step topology control (STC) scheme that reduces energy consumption while preserving connectivity in a heterogeneous sensor network without using any location-based information. This scheme can be utilized in the presence of multipath propagation or when path-loss exponents are non-uniform in a region of interest. Liu et al. (2010) developed an opportunity-based topology control algorithm, the connectivity-based topology control algorithms (CONREAP), which is rooted in reliability theory for WSNs. The CONREAP guarantees network reachability and reduces energy cost significantly. A topology maintenance mechanism should build a new topology, consume sensor's energy conservatively, and increase network lifetime. To balance energy consumption among nodes and further increase network lifetime, LoBello and Toscano (2009) provided a dynamic topology management protocol. Toscano and Bello (2008) applied a topology management protocol to create a super-frame structure where each node has an assigned time slot and data transmission is performed in a time division multiple access (TDMA) fashion. Toscano et al. provided a bounded delay for data traffic while reducing energy consumed by nodes. Üster and Lin (2011) devised a hierarchical topology and routing structure with multiple sinks, and a general data aggregation approach. An integrated topology control and routing problem was solved to improve energy efficiency and prolong lifetime of data-gathering WSNs. Rizvi et al. (2012) presented a connected dominating set (CDS)-based topology control algorithm, A1, which constructs an energy-efficient virtual backbone. The topology construction phase of A1 uses far fewer messages for an efficient algorithm than A3. It also achieves good connectivity under topology maintenance and provides better sensing coverage.

After the deployment phase, the optimal topology control mechanism should consider both topology construction and topology maintenance. Table 1 compares topology control algorithms. However, these protocols focused only on topology construction or topology management. To overcome this topology control design problem, this work proposes a novel topology control algorithm that combines topology construction and topology maintenance to extend system lifetime. Each node uses the topology control algorithm and dynamically switches its upstream node based on upstream reachable probability. In the topology construction phase, each node builds a reliable topology to ensure high network reachable probability. When a node is stable, which is assessed using the migration rule, node triggers the topology maintenance algorithm and switches to the topology maintenance process. In the topology maintenance process, a novel dynamic topology maintenance scheme is applied through a multi-level energy-threshold mechanism. When a network is not energy efficient, nodes should recreate a new topology and trigger the topology construction phase. Through this iterative process of topology control, a network can always have high reliability and be energy efficient. Additionally, the proposed distributed scheme enables nodes to autonomously create and