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Fault-Tolerant Topology with Variable-Range Transmission Power Control in Wireless Sensor Networks

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In recent years, sensor networks have been pervasive in a wide range of applications such as location tracking, earthquake report, habitats monitoring, forest surveillance, and healthcare [1]. A wireless sensor network is composed of a sink node and a large number of tiny sensor nodes that can perform computation and wireless communication. In multi-hop wireless sensor networks, sink node would flood the querying data to all sensor nodes or collect the replying information from sensor nodes. The capacity of its battery is very limited so energy consumption becomes an important issue that directly affects the network lifetime.

Topology control algorithms were proposed to maintain network connectivity with lower energy consumption. To support the multi-hop communication, a connected dominating set (CDS) is selected for establishing a virtual backbone [2–4]. The CDS includes a subset of sensor nodes that enable communication in the network.

Sensor nodes may fail during operation. A failed node in the backbone would break the connection of the network. Recent study suggested that the backbone should maintain a certain degree of redundancy for fault tolerance [5,6]. Multiple disjoint paths are thus needed for connecting every pair of nodes. The design requires more nodes in the backbone so the power efficiency is affected.

A topology control protocol with both power saving and fault tolerance, named *P-CDS* (*Power-CDS*), is developed. *P-CDS* classifies the backbone nodes in two types, primary coordinator and backup coordinator. For failure free execution, the coordinators are responsible for data transmission while the backup coordinators remain in sleeping mode. After failed transmission is detected, some backup coordinators will be activated. The topology can be recovered by adjusting the transmission ranges of the coordinators and backup coordinators. Compared to the previous approaches, *P-CDS* reduces the number of active coordinators and also saves energy. In addition, the network topology built by *P-CDS* can survive consecutive failures with appropriate settings.

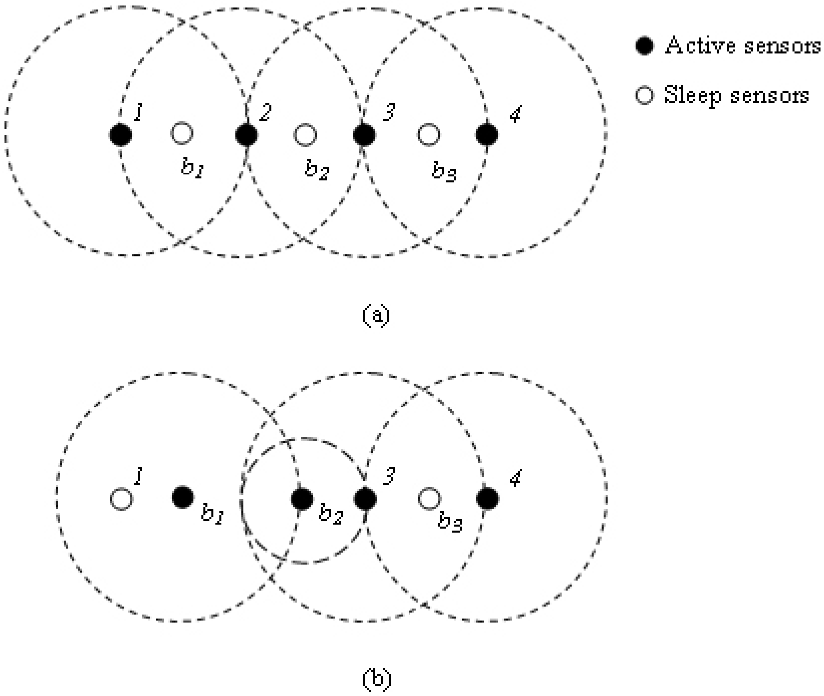

Figure 1: An example for *P-CDS*: (a) failure-free execution. (b) node 2 fails.

Two techniques are integrated in our mechanism, including scheduling the state of the coordinator and adjusting the transmission range of sensor nodes. For example, the ideal topology is shown as Figure 1 (a). Based on our mechanism, node *1*, *2*, *3*, and *4* are *primary-coordinators*; node *b*1, *b*2, and *b*3 are backup-coordinators and they switch to the sleep state after being selected. When node *2* fails, node *b*1 and *b*2 can be awakened for helping transmission (see Figure 1(b)). Node *b*1 uses the full transmission range and node *b*2 uses the half. In addition, node *1* can enter sleep mode. In this way, redundant active sensor nodes are not necessary during failure-free execution. When failure occurs, the network can be configured automatically and remain connected.

In experiments, *P-CDS* was compared with Span protocol [2] and *k*-Gossip protocol [5]. The simulations were implemented with the network simulator 2 (ns-2) [7]. To generate a network, *n* nodes were randomly placed in a 100m × 100m field to form a connected graph. The number of *n* in the region was varied from 100 to 500. The sensor nodes initial energy was set to 50J. The maximum communication range *Rmax* was set to 24m. Any two nodes with distance less than *Rmax* were considered neighbors. The traffic model utilized the Constant Bit Rate (CBR) and the source originated three packets per second. In 2-Gossip, *pk* = 0.48 was set for a high success ratio. To guarantee to construct a fault-tolerant *CDS*, *P-CDS* were evaluated with *p* = 1 and 2. In the experiments, the energy model followed the specifications of the TR 1000 radio transceiver from RF Monolithics [8,9].

The size of selected coordinators is shown in Figure 2. The size of *P-CDS* is about 57% smaller than *k*-Gossip; Span is about 12% better than *P-CDS* in sparse networks (*n* ≤ 200). In dense networks (such as 500 nodes in the region), the size of *P-CDS* is about 16.6% compared to *k*-Gossip. *k*-Gossip typically produces the larger size of *CDS* that spends more energy. Span and *P-CDS* have relatively small back-bone sizes, which increases slightly as *n* increases. Though Span produces the smaller average size than *P-CDS*, Span could not survive from sensor failures.

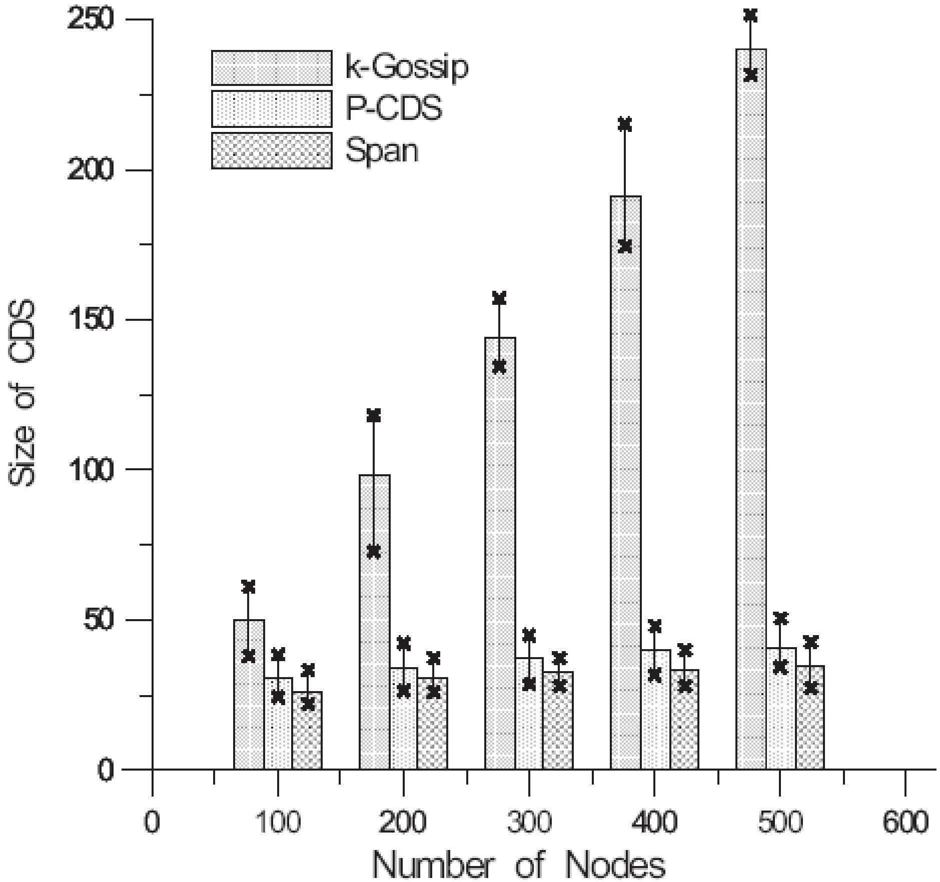

Figure 2: Size of CDS.

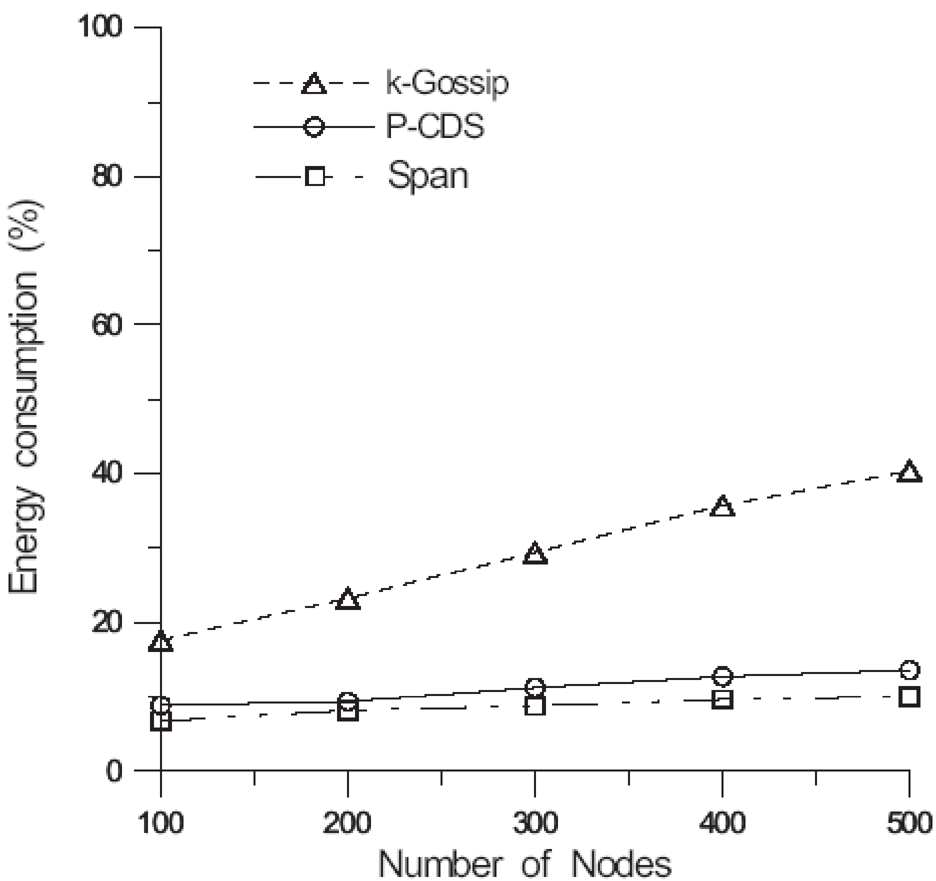

Figure 3: Comparison for broadcast cost.

Figure 3 illustrates the broadcast cost of the three protocols in terms of the transmission energy. The simulation result is quite similar to the case of *CDS* size. *k*-Gossip is still significantly higher than the other approaches because of the relatively larger size of *CDS*. When the number of nodes is 100, *P-CDS* saves about 10% of energy than *k*-Gossip. Moreover, *P-CDS* saves about 28% energy when there are 500 nodes in the region.

Based on the study and simulation results, changing transmission power on sensor nodes not only save energy consumption dramatically but improves fault tolerance with appropriate arrangements. The approach improves both network lifetime and reliability successfully.

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