Daabaj, K. (2010) *Load-balanced routing scheme for TinyOS-based wireless sensor networks.* In: IEEE International Conference on Wireless Information Technology and Systems, 28 August - 3 September, Honolulu, HI.

Load-Balanced Routing Scheme for TinyOS-based Wireless Sensor Networks

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Introduction

While the existing TinyOS-based routing protocols for wireless sensor networks (WSNs) are steadily improving for forming a reliable tree-based data gathering, it is still inferior over custom solutions with respect to energy consumption [1]. TinyOS-based routing protocols such as CTP [3] employ multifarious parameters which make them tricky to configure, they also vary widely as a function of existing load and are not as consistent as energy and load balancing across different topologies, and do not scale well for large networks. In this paper, an energy-efficient and load-balanced data collection routing scheme is proposed that leverages recent advancements over the standard network layer components provided by the TinyOS-2.x operating system for WSNs, i.e., MultihopLQI [2]. More specifically a reliable energy saving strategy based on a per-hop load balancing mechanism on the routing layer. It is evaluated on a real testbed of a hundred TelosB motes with link layers provided by TinyOS CC2420 radios, i.e., IEEE802.15.4 in outdoor interference-prone environment. The proposed routing scheme creates a routing tree based on estimated numbers of transmissions/retransmission to the base station and link quality estimation based on sequence numbers of successfully received packets. This routing scheme allows for balancing the traffic to the fluctuations in network connectivity and energy expenditure. Experimentally, the proposed routing scheme achieves an average of over 65% energy savings over the standard low-power layer currently provided by TinyOS, and achieves greater than 90% of successful packets transmission ratio. The proposed routing scheme consumes less energy for communication while reducing topology repair latency and supports various aggregation loads. As a sensible evaluation, the proposed routing scheme is compared at the early stage of its design with the noteworthy TinyOS-2.x implementation of MultihopLQI on TelosB wireless platform.

Related Work

Based on observations in the literature [1][3], the existing link quality estimators are limited in the sense that they provide only partial views of the real quality of the link. Each estimator computes one metric, with an exception of four-bit [3], which combines packet reception ratio and packet retransmissions-based estimation techniques. However, in order to better estimate link quality, it is essential to employ several metrics simultaneously. This results in estimator that is a function of several metrics, thus giving a more meaningful state of the link quality level. The combination of RSSI, LQI, and EXT would be more reliable and accurate for describing the real link status as been implemented in the proposed routing scheme. In this paper, the outdoor experiments will focus a hardware-based Channel State Information (CSI) specific on the IEEE 802.15.4 stack, the LQI field, particularly, on TolesB motes built with the CC2420 radio that provides a reliable RSSI/LQI/bit error patterns. On the other hand, since the wireless links are

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not stable in low-power WSNs, and the loss of packets happens frequently in communications, the ETX software-based routing metric is mainly used by most reliable routing protocols to make a most reliable link to be used. However, WSNs are mainly battery-powered, the energy is restricted. If we only consider the reliability of communication, some of the WSNs nodes will be exhausted rapidly. Unfortunately, the small number of exhausted sensor nodes is always very important to the whole network, if these important nodes fail to relay packets, the network's performance will be ruined. In other words, If only the reliability metrics are considered in WSNs, it may create a lot of hops route, and the high quality paths will be frequently used. This leads to shorter lifetime of the high quality routes; thereby the entire network's lifetime will be significantly minimized. As a result, On the basis of reliability metrics, a reliable, energy efficient, and load balancing routing is a key problem in WSNs.

Routing Scheme Description

The proposed routing scheme is a hybrid, reactive and proactive, designed to adaptively provide enhanced balanced energy usage on reliable routes and to employ ready-to-use neighborhood routing tables in order to allow sensor nodes to quickly find a new parent upon parent loss due to link degradation or run-out of energy. As shown in figure 1, the scheme uses Channel State Information (CSI) and residual energy capacity with other locally overheard parameters, e.g., aggregation load, sensor node-*id*, and tree-level, to form a cost function for selecting the most reliable and energy-efficient route towards the base station.

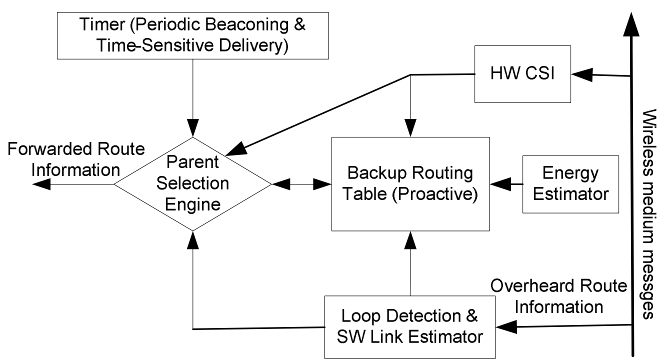

Fig. 1 Routing Scheme Overview

The routing tree is a directed acyclical graph which relays packets towards the base station over multiple paths. The routing tree is built by assigning a *level number* to each sensor node depending on its distance (e.g., number of hops) to the base station, and delivers sensing data packets from higher-level to lower-level sensor nodes. The base station is at *level* 0. Each sensor node at level *i* can select a valid parent from its level *i* or from lower level *i*-1 towards the base station. The valid parent is selected by the routing metrics used in the routing cost function, i.e., link quality, residual energy, hop-count, aggregation load or latency. Obviously, any path from source sensor nodes to the base station is the most efficient path in the resulting routing tree. The routing tree starts with the easily-constructed shortest path tree, and then allows each sensor node to pick a new parent node if it appears to provide better routing cost with a higher link quality. Using the broadcast nature of the contention-based wireless medium, a sensor node can easily observe its neighborhood by receiving and overhearing periodic beacon packets which initially originate by the base station.

At regular intervals, each sensor node transmits beacon packets to update route information. Upon parent loss, a sensor node with invalid parent waits for new beacon packets to restore a new valid parent node. During the waiting period to join its new parent, some sensor nodes may possibly discard some of their received packets due to buffer overflow of aggregation load. This waiting time is limited by delay constraints threshold in order to keep the network responsive to topological changes due to link dynamics or inconsistent energy dissipation. For instance, if the quality of the link between a sensor node and its current parent degrades under the threshold or the energy capacity of its parent is low, this sensor node will cancel its current parent and instantaneously sends out a beacon packet to inform its downstream children sensor nodes, if any, and waits a certain time until a new valid parent is selected *reactively* during the route searching phase. As soon as sensor node joins its new valid parent, it broadcast a beacon packet to inform its downstream children; but if a sensor node couldn't join a new valid parent and its parent becomes invalid for longer than the waiting time, it will select its parent from the recent updated *proactive* multipath backup to reduce the recovery delay time. Hence, the network will quickly self-organize during route searching phase by maintaining a reliable set of valid parent nodes in the built-in routing table to allow sensor nodes to quickly find a new valid parent upon parent loss due to link degradation or energy routing hole. If a sensor node's parent becomes invalid for longer than certain delay time, it searches for an alternative valid parent in its neighborhood routing table that has been updated recently. The routing scheme *proactively* caches valid parents toward the base station based on overheard neighborhood information. Once a received beacon indicates a valid path toward the base station, neighborhood management module updates the route information into the routing table. When the routing component looks up an alternative path to the base station, the lowest cost route will be selected, without waiting beacons a longer time to rediscover a route.

Results and Observations

Due to space limitation, few results are presented in this paper. The parent selection process in TinyOS MultihopLQI is merely based on link quality. When the link quality degrades, neighboring sensor nodes will choose other sensor nodes with a better link quality. Creating routing holes in MultihopLQI is straightforward due to purely relying on the best link quality. When a sensor node has the base station as one of its neighbors, the sensor node will not automatically choose it as its parent. Instead, it will choose the neighbor with the best link quality. Figure 2 shows how the proposed routing scheme performs quite well compared to MultihopLQI where the energy consumption increases steadily with the size of the neighboring nodes. Figure 3 shows the change in the node's average residual energy level after a period of data transmission. It is apparent that the average remaining energy level decreases with higher density. MultihopLQI cannot reduce the redundant data copies in the network which resulted by a high traffic load handled by each individual forwarding node. Figure 4 shows that the proposed routing scheme outperforms the MultihopLQI and delivers obviously a higher percentage of packet delivery rates in all load scenarios. This is due to the flexible selection of parent nodes and the implementation of data packets aggregation.

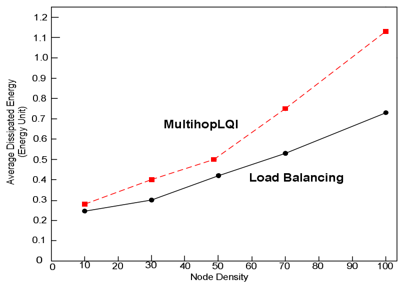

Fig. 2 Average Dissipated Energy

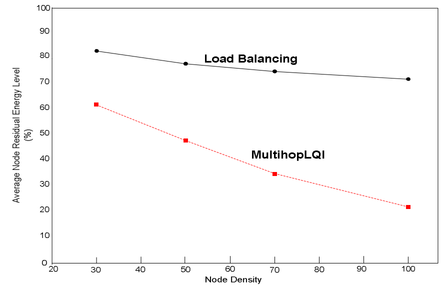

Fig. 3 Nodal Residual Energy Ratio

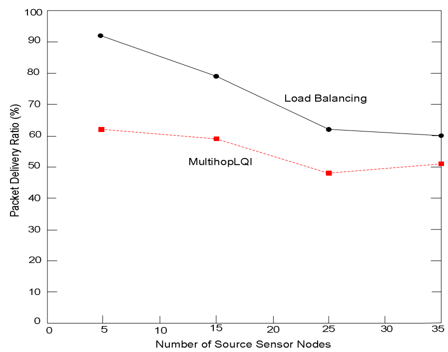

Fig. 4.10 Packet Delivery Ratio

Conclusion and Future Work

The main contribution of this paper is the design and test of a simple, reliable, and energy efficient routing scheme for sensor networks that successfully meets the goal of network longevity, and that demonstrates satisfactory robustness and network lifetime. The proposed routing algorithm allows a child sensor node dynamically searches for a new reliable parent node with more residual energy and takes in account the tradeoffs between latency and energy. This dynamic adaptation strategy can alleviate the energy hole problem. Although the use of Channel State Information (CSI) form broadcast beacons is crucial to link estimation, MultihopLQI's reliance on one form of CSI, i.e., LQI metric, is the main reason behind its inferior performance. Maximising the network lifetime is the subject of ongoing work by extending the experiments to scalable simulations on larger networks.

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