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Enhanced tree routing for wireless sensor networks

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ABSTRACT

Tree routing (TR) is a low-overhead routing protocol designated for simple, low-cost and low-power wireless sensor networks. It avoids flooding the network with path search and update messages in order to conserve bandwidth and energy by using only parent–child links for packet forwarding. The major drawback of TR is the increased hop-counts as compared with more sophisticated path search protocols. We propose an enhanced tree routing (ETR) strategy for sensor networks which have structured node address assignment schemes. In addition to the parent–child links, ETR also uses links to other one-hop neighbours if it is decided that this will lead to a shorter path. It is shown that such a decision can be made with minimum storage and computing cost by utilizing the address structure. Detailed algorithms for applying ETR to ZigBee networks are also presented. Simulation results reveal that ETR not only outperforms TR in terms of hop-counts, but also is more energy-efficient than TR.

1. Introduction

Wireless sensor networks have been identified as one of the most important technologies for the 21st century [1]. The recent advances in micro-electro-mechanical systems (MEMS) technology, wireless networking and inexpensive low-power processors have been making these so-called "intelligent sensors" increasingly smaller and cheaper. It is widely predicted that large set of wirelessly connected sensors which are unattended and disposable will proliferate in a broad range of potential applications including academic, industrial, agricultural, domestic and military applications.

One of the major constraints of wireless sensor networks is the limited energy supply. The on board batteries are required or expected to last for months, years or virtually forever. A solar power supply is not feasible for many of the applications due to its cost, physical size and deployment requirements. Since all node activities (sensing, computing and communicating) consume power, every aspect of the design, deployment and management of wireless sensor networks have to be energy-efficient to meet stringent power requirements. Especially, radio communication is the most expensive operation a node performs in terms of energy usage, and thus it must be used sparingly and only as dictated by the task requirements [2]. In addition to scarce energy supply, modest processing power and memory are also typical characteristics of sensor nodes. All these issues have a profound impact on routing strategies of modern wireless sensor networks.

Since the transmit power of a wireless radio is proportional to distance squared, multi-hop topology where data packets are relayed via intermediate nodes consumes less energy than direct communication over long distances. More importantly, sensor nodes are normally scattered over a large area of interest where multi-hop transmission is the only practical way to move data across the network. For some applications, multi-hop structures could be utilized to improve network robustness and scalability as well [2]. Networking, therefore, is an essential function of multi-hop wireless sensor networks. Routing is the networking mechanism built into the firmware of each sensor node for establishing paths between source and destination nodes.

Various routing algorithms have been proposed for wireless sensor networks [2,3, and the references therein].

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Normally a routing algorithm has a search phase where the optimum route (in terms of certain metric such as minimum link cost or least hop-count) is determined based on certain information about the destination, such as address, location, type of sensor or in possession of some other attributes. In addition, a route recovery and/or update procedure take place when a route is broken or a topology change is detected. To various degrees, those routing algorithms require internode communication of the whole or a large portion of the network in finding the path. The return for the associated cost in computing, storage and communication is the optimum path created between the source and destination nodes. Those algorithms could be the most suitable candidates for many applications.

Some sensor networks are constructed in such a way that it starts with a root node and grows as new nodes join the existing nodes as child nodes. Each node has one and only one parent while a parent can have multiple children. The resultant network structure is like a tree as depicted in Fig. 1 where the links connecting nodes represent parent–child relationship. In Fig. 1, node *a* is the root node and nodes *b, c* and *d* are the child nodes of *a*. Nodes *e* and *f* are children of *d*. Both nodes *a* and *d* are ancestors of *e* and *f* while all nodes except *a* are descendants of the root node *a*.

Tree routing (TR) is a simplified routing algorithm proposed for such networks. In TR, internode communication is restricted to parent–child links only. That is, while the network's physical topology is quite complex, the logical tree topology is used for data forwarding. By relying solely on the parent–child links, tree routing eliminates path searching and updating and, therefore, avoids extensive message exchanges associated with those procedures. TR is most suited for networks consisting of small-memory, low-power and low-complexity lightweight nodes. TR could also be used by a node at some operation stages such as when its battery supply is below certain threshold. The main drawback of TR is the increased hop-counts as compared with more sophisticated path search protocols.

One feature which is not fully utilized by TR is the neighbour table. Each node on almost all sensor networks contains a neighbour table which records some information such as addresses of nodes within its radio range. The neighbour table naturally contains the parent node and child nodes and may contain some other nodes. The neighbour table is normally built up during a node's join process when it scans its neighbourhood in order to discover its neighbours and find a potential parent to join [4,5]. The ZigBee standard requires the neighbour table be kept up-to-date. This can be achieved, for example, by periodically scanning and/or monitoring the neighbourhood. In the AODV routing protocol [6], a node keeps track of its neighbours by listening for a HELLO message that each node broadcasts at set time intervals.

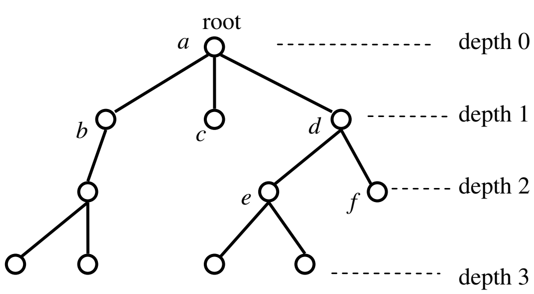

Fig. 1. The logical tree structure.

Making further use of the neighbour table and taking advantage of the node address relationship inherent in certain address assignment schemes, this paper proposes an enhanced tree routing (ETR) algorithm. In addition to the parent–child links, ETR also uses the links to other one-hop neighbours if it is decided that this will lead to a path which is shorter (in terms of number of hops) than the tree path. It will be shown that such a decision can be made with minimum storage and computing cost by utilizing the address structure. Detailed algorithms for applying ETR to ZigBee networks will be presented and simulations will be conducted to evaluate the performance of ETR in terms of both hop-counts and energy consumption.

This paper is organized as follows. Section 2 reviews the related work. Section 3 presents the proposed ETR protocol. Section 4 applies ETR to ZigBee networks. Section 5 provides the simulation results and Section 6 concludes the paper.

2. Related work

Various routing mechanisms which are different from the traditional TCP/IP addressing have been proposed for wireless sensor networks. They have considered the characteristics of the network along with the application and architecture requirements.

In data-centric routing, the node desiring certain types of information sends queries to certain regions and waits for data from the nodes located in the selected regions [7,8]. Hierarchical protocols [9,10] group nodes into clusters where cluster heads are responsible for intra-cluster data aggregation and inter-cluster communication in order to save energy. Location based protocols utilize the position information to increase the energy efficiency in routing by relaying the data to the desired regions rather than the whole network [11]. Algorithms which search for alternatives to the parent–child links have recently been proposed specifically for ZigBee networks [12,13]. However, this paper will propose a more general protocol and provide a deeper and more comprehensive study on this matter.

One routing protocol proposed for general ad-hoc networks which has received great attention is the AODV protocol [6]. AODV uses hop-count as the metric and tries to find the shortest route possible. It is a reactive routing protocol, meaning that it establishes a route to a destination only on demand. In particular, when a node requires a route, it initiates a route discovery procedure broadcasting route request (RREQ) messages. When a node receives a RREQ, if either it has a valid route entry to the demanded destination or it is the destination itself, it creates and sends a route reply (RREP) message back to the originator node. Every node maintains route entries with forward and