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Extended shortcut tree routing for ZigBee based wireless sensor network

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ABSTRACT

Energy efficiency and network lifetime are main concerns in WSN. In order to improve these factors ZigBee plays an important role. Low cost, low data rate features of ZigBee results in low power consumption and makes it useful in wireless sensor networks, increasing life of small batteries of nodes in the network. Since tree routing in ZigBee does not require any routing tables to send the packet to the destination, it can be used in ZigBee end devices that have limited resources. Routing protocols such as AODV (Ad-hoc on demand distance vector routing), ZTR (ZigBee tree routing), and STR (Shortcut tree routing) are compared on the basis of different performance metrics (End to end delay, routing overload, throughput, packet delivery ratio). An extensive simulation in NS2 is carried out. The performance evaluation shows that STR achieves better performance as compared to other two routing protocols. But there are some limitations of the STR method. Performance of packet delivery ratio of STR is less as compared to AODV. Performance of end to end delay of STR is poor as compared to AODV. Hence ESTR is proposed. The main aim of proposed ESTR [Extended STR] is to present new ZigBee network routing protocol with goal of improving the performance of ESTR in terms of PDR and delay against STR and AODV.

1. Introduction

ZigBee is a specification that defines a set of high level protocols for low cost and low power [5] wireless personal area networks. ZigBee is based upon IEEE 802.15.4 standard [1,8,9]. ZigBee provides the low power wireless mesh networking and supports up to 64,000 devices in a network with the multihop tree and mesh topologies as well as star topology [3,4,7]. It is different from the other personal area network standards such as Bluetooth [6], UWB, and Wireless USB. Based on these characteristics, ZigBee Alliance has various applications like smart home, building automation, health care, smart energy, telecommunication, and retail services. The ZigBee network layer, which is the core of the standard, provides dynamic network formation, addressing, routing, and network management functions. Every node is assigned a unique 16-bit short address dynamically using either distributed addressing or stochastic addressing scheme. The routing protocols of ZigBee are diverse so that a system or users can choose the optimal routing strategy according to applications. ZigBee reactive routing protocol provides the optimal routing path for the arbitrary source and destination pair through the on-demand route discovery. It requires the route discovery process for each communication pair, so the route discovery overhead and the memory consumption proportionally increases with the number of traffic sessions.

In ZTR, since each node is assigned a hierarchical address [2], a source or an intermediate node only decides whether to forward a packet to the parent or one of the children by comparing its address with the destination address. ZigBee tree routing (ZTR) uses distributed block addressing scheme

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and prevents the route discovery overhead in both memory and bandwidth. The main advantage of ZTR is that any source node can transmit a packet to an arbitrary destination in a network without any route discovery overheads.

ZTR cannot provide the optimal routing path, as packets are forwarded only by using tree topology to the destination even if the destination is located nearby, though it does not require any route discovery overhead.

Shortcut tree routing (STR) significantly enhances the path efficiency of ZTR by only adding the 1-hop neighbor information. Whereas ZTR only uses tree links connecting the parent and child nodes, STR uses the neighbor nodes by shortcutting the tree routing path in the mesh topology. In STR [2], a source or an intermediate node selects the next hop node having the smallest remaining tree hops to the destination regardless of whether it is a parent, one of children, or neighboring node. The routing path selection in STR is decided by individual node in a distributed manner. STR has the limitation that the routing path is not always optimal in an aspect of the end-to-end hop distance, because the next hop node is selected based on the local information like 1-hop neighbor table.

Our objective is to provide the near optimal routing path like the reactive routing protocol as well as to maintain the advantages of ZTR such as no route discovery overhead and little memory consumption for the routing table.

Hence we propose ESTR, which is fully compatible with the ZigBee standard that applies the different routing strategies according to each node's status. Also, it requires neither any additional cost nor change of the ZigBee standard including the creation and maintenance mechanism of 1-hop neighbor information. The Source Initiated Bulged Multi-Path Routing scheme provides multiple disjoint paths from source to destination. Hop count of all nodes is considered from sink. In this, only one path from each node is considered which is one hop away and is having hop count less than that of the source node. The current reporting rate is divided by number of upstream neighboring nodes of source and this new reporting rate is assigned over each path. The node will receive the packet and forward it only if it is from that dedicated path, else it will discard that packet. This process will be carried till packet reaches to destination.

The main contributions of this paper are as follows: First, ESTR is proposed to resolve the main reasons of overall network performance degradation of ZTR and STR, which are the detour path problem and the traffic concentration problem. Second, it is proved that the multipath routing used by ESTR improves the routing path efficiency and alleviate the traffic load concentrated on tree links in ZTR. Third, analyze the performance of ESTR, STR, and AODV.

This paper is organized as follows: Section 2 describes ZTR and STR and their problems. Section 3 presents the extended shortcut tree routing algorithm and analyses the properties of ESTR in a mathematical way. The diverse performances are evaluated in Section 4, and conclusion is given in Section 5.

2. ZigBee tree routing

ZTR is designed for resource constrained ZigBee devices to choose multihop routing path without any route discovery procedure, and it works based on hierarchical block addressing scheme.

With the hierarchical addressing scheme, we can easily identify whether the destination is descendant of each source or intermediate node. In ZTR, each source or intermediate node sends the data to one of its children if the destination is descendant; otherwise, it sends to its parent. The example of the routing path of ZTR is described in Fig. 1a and b, where a packet is routed through several hops toward the destination even though it is within the range of sender's 2-hop transmission range. To solve this detour path problem of ZTR, ZigBee specification has defined the direct transmission rule that allows a coordinator or a router to transmit a packet directly to the destination without decision of the routing protocol as shown in Fig. 1a, if the corresponding destination is in the neighbor table.

However, this method cannot fundamentally solve the detour path problem of tree routing, as shown in Fig. 1b. In case that the destination is located more than 2-hop distance away from a source node, we cannot apply the direct transmission rule. In addition to the detour path problem, ZTR has the traffic concentration problem due to limited tree links. Since all the packets pass through only tree links, especially around the root node, severe congestion and collision of packets are concentrated on the limited tree links. This symptom becomes worse and worse as the number of packets increases, and it finally causes the degradation of the packet delivery ratio, end-to-end latency, and other network performances.

3. Shortcut tree routing

STR algorithm solves these two problems of the ZTR by using 1-hop neighbor information. It solves detour path problem completely but traffic concentration partially. The STR algorithm basically follows ZTR, but chooses one of neighbor nodes as the next hop node when the remaining tree hops to the destination can be reduced. For example, in Fig. 1c, STR computes the remaining tree hops from the next hop node to the destination for all the neighbor nodes, and selects the N4 as the next hop node to transmit a packet to the destination D2. The main idea of STR is that we can compute the remaining tree hops from an arbitrary source to a destination using ZigBee address hierarchy and tree structure as discussed in previous section. In other words, the remaining tree hops can be calculated using tree levels of source node, destination, and their common ancestor node, because the packet from the source node goes up to the common ancestor, which contains an address of the destination, and goes down to the destination in ZTR.

STR has the limitation that the routing path is not always optimal in an aspect of the end-to-end hop distance, because the next hop node is selected based on the local information like 1-hop neighbor table. For example, in Fig. 1c, the optimal path from S to D2 is S-N5-D2, but, it requires 2-hop neighbor information in order for the source S to know that N5 is within 1-hop communication range of theD2. It is obvious that maintaining 2-hop neighbor information incurs high protocol overhead in the network with high node density; thus, we selected to provide a resource efficient routing