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A Survey on Different Tree Routing Mechanisms Used by Zig Bee Wireless Networks

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ABSTRACT

ZigBee, a unique communication standard designed for low-rate wireless personal area networks, has extremely low complexity, cost, and power consumption for wireless connectivity in inexpensive, portable, and mobile devices. The IEEE 802.15.4 protocol is a promising standard for WSN applications because it pays particular attention to energy efficiency and communication overheads. ZigBee uses Ad-Hoc On-demand Distance Vector (AODV) and Tree Routing (TR) as a routing protocol. In TR protocol, the packets follow the tree topology for forwarding the data to the sink node even if the sink node is located near to the source node. In this paper a survey on different tree routing mechanisms used by ZigBee wireless networks are presented.

I. INTRODUCTION

Wireless sensor network (WSN) becomes an important topic for researchers in recent year. IEEE 802.15.4 is the standard for WPAN which provided physical (PHY) and medium access control (MAC) layers [1]. This standard support a low cost, low power and low data rate which is well-suited for WSN. IEEE 802.15.4 networks support star, mesh, and cluster-tree network. This network consist of two types of devices; (1) Full Function Device (FFD) and (2) Reduce Function Device (RFD). FFD can play a role of a router which can connect to other FFD and RFD devices. On the other hand RFD can only connect to FFD devices.

ZigBee is a low-cost, low-power consuming energy based on the IEEE 802.15.4 standard for wireless personal area networks (WPANs). The low cost of ZigBee Network allows the technology to be widely deployed in different wireless applications and the low power-usage allows for extending network life time with smaller batteries. ZigBee specification [2] defined the top layer of IEEE 802.15.4 from network layer to application layer. Fig.1 shows ZigBee protocol stack. ZigBee network defines three kinds of devices personal area network (PAN) coordinator, router, and end device.

Personal Area Network (PAN) coordinator is a FFD device acting as the core component of the network and responsible to initiate the network by setting network's parameters which contain how many nodes can join to and the types of nodes (router and end devices) in this network. After setting up the network, PAN coordinator is responsible to accept or reject nodes depending on network parameters and also handles the routing of packets through nodes.

Router device is a FFD device that a PAN coordinator uses it as intermediate node to carry out the multi-hops routing message through the network from source nods to the sink node.

End device is a RFD device acting as the leaf of the network with limit functionality. It is work for the purpose of sensing data from the environment and transmits to router device which is joined through it to the network.

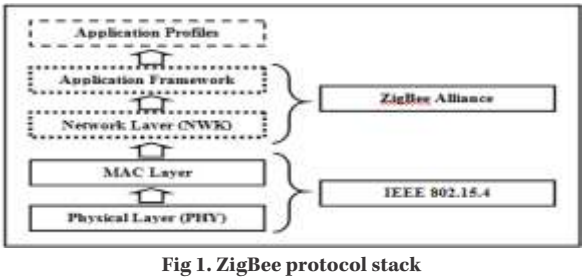

Fig 1. ZigBee protocol stack

Routing strategy in ZigBee uses a combination of two kinds of routing protocol as default. One is Tree Routing (TR) protocol and another is Ad Hoc On-demand Distance Vector (AODV) protocol. The addressing scheme for the nodes in this network uses distributed addressing scheme which follows the tree topology construction. In TR protocol when node senses data from environment and wants to send it to the sink, it first checks if the destination address is in the address space of the node, this means that node is its descendant. If this is the case the source node simply forwards the packet downwards to its descendant. Otherwise it forwards the packet upwards to its parent node. When the parent or descendant node received this packet they will select the next hop node according to the destination address following the same manner.

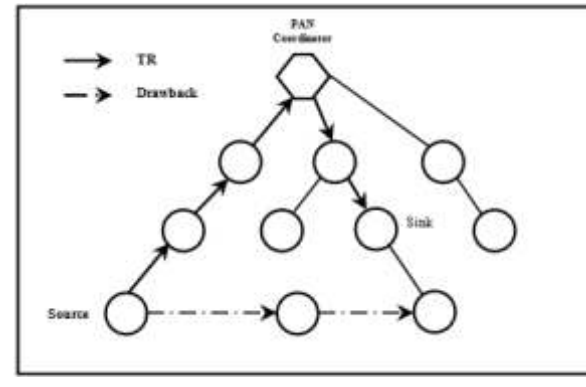

Fig.2 Drawback in TR protocol

TR protocol is able to find the next hop node for a given sink address without routing table. However, the sender node does not know if the sink is located nearby or if it is not in the sub-tree. Fig.2 shows the drawback of TR protocol.

II. TREE ROUTING (TR) PROTOCOL

In TR [3] protocol, an FFD device which is a router device called coordinator, is responsible to initiate the network by choosing certain key of network parameters. Other nodes can join the network by becoming the children of the existing node. In TR protocol, the network addresses are distributed in tree structure in which coordinator uses zero network address while the non-coordinator nodes have the non-zero address. The addresses are computed by the parent node based on its own network address and the network address of its children. When the tree address allocation is enabled, the network addresses are assigned using a distributed address allocation scheme. This is a scheme which is designed to provide potential parents with a finite sub-block of network addresses to be distributed to its children. The

size of the sub-block depends on the following parameters: maximum number of children per parent, maximum number of router children a parent can have and maximum depth of the network. Depending on these parameters and the depth of the node, d, if node wants to join the network, router node computes the address block size for each of its router child. The TR protocol eliminates path search by solely following the parent-child link.

III. COMPARATIVE STUDY

A. Improved TR Routing Protocol (ImpTR)

This method is used to enhance the tree routing by utilizing neighbor nodes. This algorithm follows ZigBee tree routing but chooses neighbor nodes as next hop node, only if the path via the neighbor node toward destination is shorter than the path when using TR protocol. Improved Tree Routing (ImpTR) [4] protocol is proposed by using neighbor table, same structure address scheme of ZigBee networks and using symmetrical relationship between nodes. If node A is a neighbor of node B, node B is also a neighbor of node A. Each node in the network contains a neighbor table. This table contains information like parent node, child nodes, personal area network identifier, MAC address, network address, device type and relationship. This neighbor table is normally built during a node joining process when node scans its neighborhood in order to discover its neighbor and find potential parent to join. This neighbor table is updated by periodically scanning the neighborhood.

Consider a configuration shown in Fig. 3. Node 7 wants send data to node 9; each node has a neighbor table which contains the information about its neighbor within the transmission range. The improvement of this protocol consists of six steps. It starts by checking if the sink address is one of the descendants of the source node. If it is, it will send the data directly to its descendants. Otherwise it will continue with the following steps:

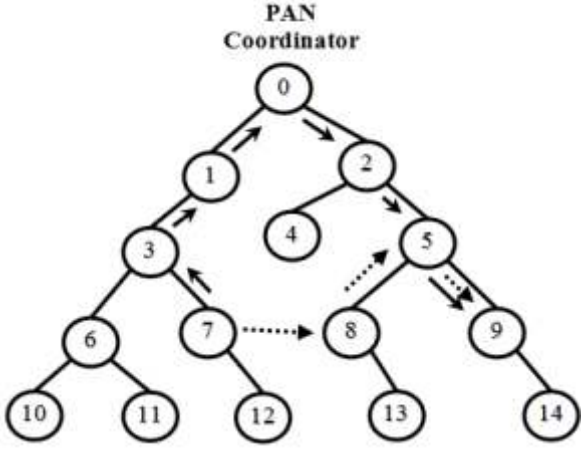

Fig. 4 The proposed ImpTR protocol

Step1: source node checks if the sink node is its parent node. This is done by calculating the parent address and comparing it with sink address.

Step 2: source node checks if the sink address is one of its neighbors. If yes, the source node transmits data packets to the corresponding node.

Step 3: source node checks if the sink address is one of its neighbor's descendants. If it is first packets will be transmitted to the neighbor node. When the neighbor node receives these packets it will check the algorithm and find that the sink node is one of its child. If there is more than one neighbors satisfying this, the source node chooses the one with highest depth which is the nearest node to the sink.

Step 4: source node checks if the sink node is one of the neighbor ancestors by calculating the ancestor addresses of the neighbor node. Then it compares each ancestor with sink node. Clearly since the coordinator is common ancestor of all nodes.

Step 5: source check if the sink node is in the address space of neighbor's parent. This is done by finding neighbor's parent address and after that the source node will transmit packets to its neighbor. The neighbor node then transmits data packets to its parents. If all the steps are not satisfied, parent node finds that the sink is one of its children nodes packets downward to its child. Fig. 4 shows this case by sending data from node 7 to node 9.

Step 6: If all the above steps are not satisfied the source node will transmit the packet to parent node and follow the tree-base algorithm.

B. ZigBee Tree Routing (ZTR)

ZigBee tree routing (ZTR) [5] prevents the route discovery overhead in both memory and bandwidth using the distributed block addressing scheme. In ZTR, since each node is assigned a hierarchical address, 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. The most benefit of ZTR is that any source node can transmit a packet to an arbitrary destination in a network without any route discovery overheads. Due to this efficiency, ZTR is considered as a promising protocol for resource constrained devices in diverse applications such as smart grid project and Internet of Things (IoT). However, in ZTR, packets are forwarded along the tree topology to the destination even if the destination is located nearby. Thus, ZTR cannot provide the optimal routing path, while it does not require any route discovery overhead.

The major problems faced by ZTR are detour path problem and traffic concentration problem. Detour path problem, 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. 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.

C. Shortcut Tree Routing (STR)

Shortcut tree routing (STR) [6] 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 exploits the neighbor nodes by focusing that there exist the neighbor nodes shortcutting the tree routing path in the mesh topology. In other words, in STR, 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, and STR 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 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. 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.

D. Performance Analysis

The performance of the tree routing mechanisms described here can be analyzed based on certain parameters that are listed in Table 1. Average end-to-end delay is the time needs to transmit application

packets from the source node to destination node divided by the number of received packets in destination node. Average throughput is the number of application packet that received in the destination node correctly divided by simulation time. Energy consumption is the energy remains in the network after simulation time finish. It is calculated by setting an initial energy to all nodes in the network (all nodes have the same initial energy), and set the other energy parameters the receiving power, transmitting power, idle power, and sleeping power. The following formula is used to calculate the energy consumption:

Energy consumption = initial energy – remaining energy

Tree Routing Mechanism	Energy Consumption	Detour path problem	End to End Delay	Average Throughput	Traffic concentration Problem	Route Discovery Overhead
Imp TR	High	Yes	High	Low	Yes	High
ZTR	Comparatively low	Yes	Medium	Medium	Yes	Comparatively high
STR	Low	No	Low	High	No	Low

Table 1. Performance analysis of the tree routing mechanisms

The fundamental problems of the general tree routing protocols are detour path problem and traffic concentration problem, which cause the overall network performance degradation.

IV. CONCLUSION

The ZigBee tree routing is widely used in many resource-limited devices and applications. It has the fundamental limitation that a packet follows the tree topology; thus, it cannot provide the optimal routing path. The fundamental problems of the general tree routing protocols are detour path problem and traffic concentration problem, which cause the overall network performance degradation. To overcome these problems, STR that uses the neighbor table, originally defined

in the ZigBee standard. In STR, each node can find the optimal next hop node based on the remaining tree hops to the destination. The analyses prove that the 1-hop neighbor information in STR reduces the traffic load concentrated on the tree links as well as provides an efficient routing path. From the survey on different tree routing mechanisms in ZigBee wireless networks, we concluded that the best method is Shortcut Tree Routing.

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