Improved Tree Routing (ImpTR) Protocol for ZigBee Network

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Summary
Many application scenarios in wireless sensor network (WSN) require connectivity between nodes to transmit the collected data to a sink node. ZigBee is a standard for wireless personal area network (WPAN) based on IEEE 802.15.4. It has been developed for low cost, low data rate and low power consumption. 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, we present an enhancement of the TR protocol called Improved Tree Routing (ImpTR) protocol. The new ImpTR protocol determines the shortest path to the sink node depending on the neighbor table instead of following the tree topology. The packets are forwarded to the neighbor node if the path to the destination through neighbor node is shorter than the path through PAN coordinator. Results show that the proposed algorithm provides shorter average end-to-end delay, increase throughput and decrease the energy consumption from the network when compared to the original TR routing protocol.

Key words:
IEEE 802.15.4, ZigBee, Neighbors-Table, Tree Routing, NS-2

1. 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) (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:

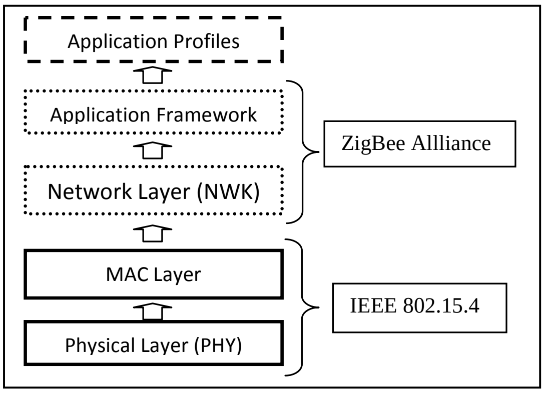

Fig. 1 ZigBee protocol stack

i. 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 also handles the routing of packets through network nodes and chooses the routing techniques in the network. In ZigBee network it has one coordinator which is mostly connect to the power supply.

ii. 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. Also router device can accept another router or end device node to join the network by assigning network address to this new node and create a communication link

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between them. This link will use to transfer data packets to sink node.

iii. 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. End device can't accept any device to join the network and it has limit energy for that it going to sleep mode to save its energy.

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.

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. In order to mitigate this drawback we propose a protocol called Improved TR (ImpTR) protocol. This protocol is more efficient than the original TR protocol by employing neighbours-table which is part of the existing ZigBee network specification. Our algorithm improves the original TR protocol by choosing the next hop toward the sink by comparing all neighbour nodes to find the shortest path to the sink. Our results show that ImpTR protocol reduce the average end to end delay by 25%, increase average throughput by 55%, and save a round 18% of the energy consumption from the network as compared to the original TR protocol.

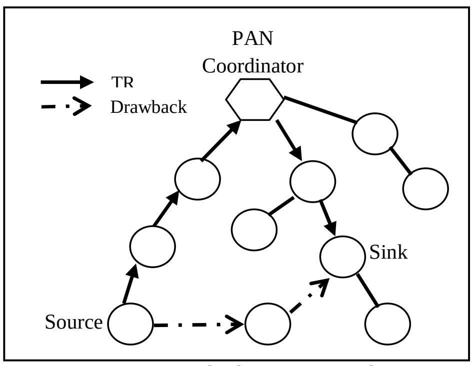

Fig.2 Drawback in TR protocol

This paper is organized as follows. Section 2 explains routing challenges in WSN. Section 3 reviews related works. The overview of TR protocol is presented in Section 4. Section 5 describes the proposed improvement on TR protocol. Section 6 discusses the simulation results of the proposed improved TR protocol and we conclude our paper in Section 7.

2. Routing Challenges in WSN

The design of routing protocol in WSN is influenced by many challenges due to several characteristics that differentiate WSN from other wireless network. These challenges must be overcome to achieve efficient communication in WSN.

First despite the development in microsensor technology, sensor nodes are tightly constrained because of limited resources (energy, storage memory, transmission power) thus it require careful management and efficient routing protocol to maximize the network lifetime and minimize energy expenditure from the network. Second, routing scheme should be scalable to work with a large number of nodes and response to any events happen in the phenomena or any changing in the network topology [3]. Third, most of the applications in WSN require to transmit the data from different source nodes to one sink node, for that routing protocol should have the ability to handle this kind of data. Forth, when sensor nodes deploy in environment it's happen that some sensors generate similar value of attribute such data redundancy needs to be handle by routing protocols to improve the performance of the network.

Due to such differences, many algorithms have been proposed to solve these problems of routing protocol in wireless sensor networks. These routing mechanisms have considered the characteristics of sensor nodes along with the application and architecture requirements.

3. Related Works

Various routing protocols have been proposed for WSNs. Directed Diffusion in [4] is a data-centric protocol. In this protocol when sink node wants to get data from sensor nodes it will send out query message to the whole network. If some nodes have matched data, they will send data to sink node using one of the gradients toward sink node. Low-Energy Adaptive Clustering Hierarchy (LEACH) [5] is one of the first hierarchical routing approaches for WSNs. It uses localized coordination to enable scalability and robustness for dynamic network, and allow the system to cope with additional loads without degrading the service. In [6] Power-efficient Gathering in Sensor Information System (PEGASIS) forms chains from sensor nodes. One node will be selected from the chains to gather all the data packets from the neighbour nodes in the chains and transmit it to the sink node. Hierarchical- PEGASIS [7] is an enhancement of the PEGASIS protocol to reduce the delay during transmitting data packets to sink node. This has been done by pursuing simultaneous transmissions of data messages and considering *(energy x delay)* metric.

In [8] a shortcut tree routing is proposed to enhance tree-routing in ZigBee network by using neighbor-table. In this protocol source nodes compare all neighbor nodes within transmission range to find a node which has a smallest tree level for transmitting data packets. Another improvement proposed in [9] named hybrid routing, also utilize neighbor table finding the next hop depending on source, neighbor and sink node depth.

Ad-hoc On Demand Distance Vector (AODV) is one of the routing protocol specific in the ZigBee network [2]. It determines unicast routes to destinations within the multi-hop wireless network. If source node wants to transmit data, it will broadcast Route Request (RREQ) messages to the whole network. When intermediate node receives this routing request and does not have any routing toward the destination, it will rebroadcast the RREQ. If the intermediate node has a routing path to destination node or it is the destination node it will send back a Route Reply (RREP) message which will create a route toward the destination. If the source node received many RREPs it will compare all the routes and choose one of them with minimum number of hops.

4. Tree Routing (TR) Protocol

In TR 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 [10]. 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:

Cm: Maximum number of children per parent.

Rm: Maximum number of router children a parent can have.

Lm: Maximum depth of the network.

Depending on these parameters (*Cm*, *Rm*, and *Lm*) and the depth of the node, *d*, if node wants to join the network, router node computes *Cskip(d)* using Equation (1) which is the address block size for each of its router child:

$$Cskip(d) = \begin{cases} 1 + Cm(Lm - d - 1) & Rm = 1 \\ \dfrac{1 + Cm - Rm - CmRm^{Lm-d-1}}{1 - Rm} & otherwise \end{cases} \quad (1)$$

Where $d = 0,1,....., Lm - 1$

When a new node joins the network via a router node with address, P_A as its n^{th} child, the node P_A becomes its parent. The node P_A assigns the child node the address, C_A using the following equation:

$$C_A = \begin{cases} P_A + Cskip(d).(k-1) + 1 & (1 \le k \le Rm), \quad if\ RFD \\ P_A + Cskip.\ Rm + k - Rm & (Rm < k < Cm), \quad if\ FFD \end{cases} \quad (2)$$

where *k* is the child address [11]:

The TR protocol eliminates path search by solely following the parent-child link. When a source node with address, at depth, d wants to transmit data, it has to satisfy equation such that destination address, is one of its descendant as:

$$S_A < D_A < S_A + Cskip(d-1) \quad (3)$$

Otherwise it transmits the packet to its parent node using the following equation:

$$P_A = S_A + 1 + \left[\frac{D_A - (S_A + 1)}{Cskip(d)} \right] \times Cskip(d) \quad (4)$$

The advantage of tree routing is that it is simple and requires neither a routing table nor complexity. It only considers parent–child relationship to transmit data and ignores the neighbour nodes even if in cases in which destination address is within a single or a few hops from source node. This may cause an inefficient routing when it is routed through many hops by Zigbee tree routing algorithm. Fig. 3 shows TR protocol.

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if ( D_A == S_A descendent)
 Next hop = D_A   *Downward along the
                  tree*
else
Next hop = P_A  *upward along the tree*
end if
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Fig. 3 Tree Routing Protocol

5. The Proposed Improved TR Routing Protocol (ImpTR)

In this section we explain our proposal to enhance the tree routing by utilizing neighbor nodes. This proposed 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. An Improve Tree Routing (ImpTR) 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. 4. 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 descendents of the source node. If it is, it will send the data directly to its descendents. Otherwise it will continue with the following steps:

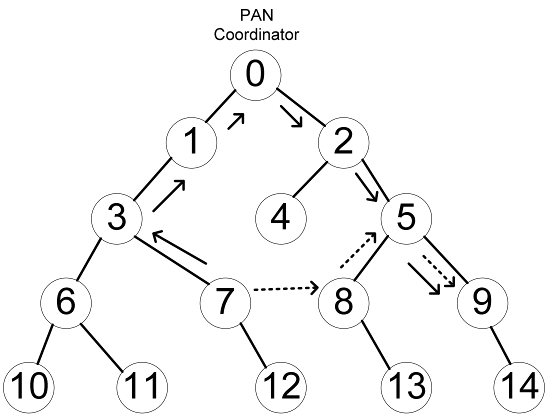

Fig. 4 The proposed ImpTR protocol.

Step1: source node checks if the sink node is its parent node. This is done by calculating the parent address using equation (4) and comparing it with sink address.

Step 2: source node checks if the sink address is one of its neighbors, N_A. 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 descendents using Equation (5). 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 equation, the source node chooses the one with highest depth which is the nearest node to the sink [11].

$$N_A < D_A < N_A + Cskip(d(N_A)-1) \qquad (5)$$

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, $P_{NA(d)}$ is parent address of neighbor node at depth *d*, every node has $P_{NA(0)} = 0$, Fig. 5 shows the algorithm that calculates the ancestor address and compares it with sink node address.

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 using equation (4) after that check the equation (6) if (6) is satisfied the source node will transmit packets to its neighbor. The neighbor node then transmits data packets to its parents using equation (4). If use 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.

$$P_{NA} < D_A < P_{NA} + Cskip\,(d(P_{NA})-1) \qquad (6)$$

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 using (4).

$P_{NA(0)} = 0$
for (i=1; i<Lm; ++i)
$$P_{NA(i)} = P_{NA(i-1)} + \left\lfloor \frac{N_A - P_{NA(i-1)} - 1}{Cskip(i-1)} \right\rfloor \times Cskip(i-1)$$
*Calculate neighbor node ancestor *
if ($P_{NA(i)} = N_A$)
break;
end for
for (j=0; j<Lm; ++j)
if ($P_{NA(j)} = D_A$)
compare if neighbor ancestor is the sink node
Next hop= N_A
break;
end for
else continue to step 5

Fig.5 : Calculates the ancestors address

6. Simulation Results

In this section we present the evaluation of the proposed ImpTR protocol using NS2 simulation. We proposed a scenario of 100 nodes deployed randomly in the network size 200m×200m with transmission range for each node 20 meter, Traffics sources are Constant Bit Rate (CBR), and the duration time of the simulation is set to 300sec. The maximum network parameters ***(Cm, Rm, Lm)*** are (5, 5, 6).

The evaluation of our work is based on the following performance metrics:

a. Average end-to-end delay :
It is time needs to transmit application packets from the source node to destination node divide by the number of received packets in destination node.

b. Average throughput :
It is the number of application packet that received in the destination node correctly divided by simulation time.

c. Energy consumption:
It is the energy remains in the network after simulation time finish. We calculate 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

In this scenario we increase the number of source node from 1 to 25 nodes without changing the number of nodes in the environment and each neighbor table is allowed to keep 12 neighbors. Results of average end-to-end delay, average throughput and energy consumption are discussed in the next section for Case I, Case II, and Case III respectively.

Case I:
Fig. 6 shows the simulation results of the proposed ImpTR protocol in comparison to the original TR protocol in terms of average end to end delay. Our proposed ImpTR protocol reduces average end-to-end delay by 25%. When the number of source nodes increase the traffic in the network increases too. Hence effect is the average end-to-end delay. The enhanced algorithm able to reduce the delay since the source node by checking the most appropriate path to choose in transmitting the data packets to the destination node. In contrary original TR protocol sends all packets to the PAN coordinator then coordinator will transmit to destination node by following the long path which will increase the delay for transmitting the packets.

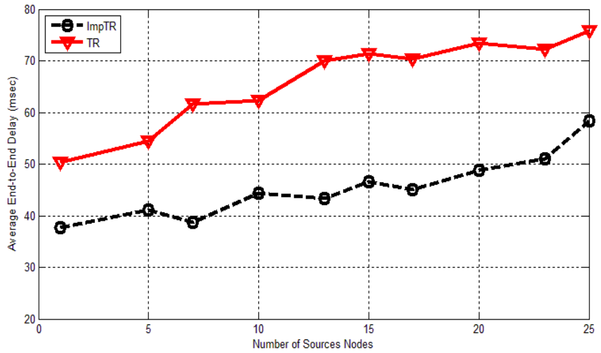

Fig.6 Average end to end delay (msec) with different sources.

Case II:
In Fig. 7 average throughput achieved using the ImpTR protocol increased by 55% this because ImpTR will reduce the load on PAN coordinator by choosing another path to destination node. On the other hand TR transmit all data to the PAN coordinator increasing the load in PAN coordinator. Hence congestion and the packet loss results in.

Case III:
Fig. 8 shows the energy consumption from the network. When the number of sources increase the energy consumption increases because the number of hops needed to transmit packets from source nodes to destination node increased. The proposed ImpTR improves the energy by 18% due to less number of hops to deliver packets to destination node compared with original TR protocol.

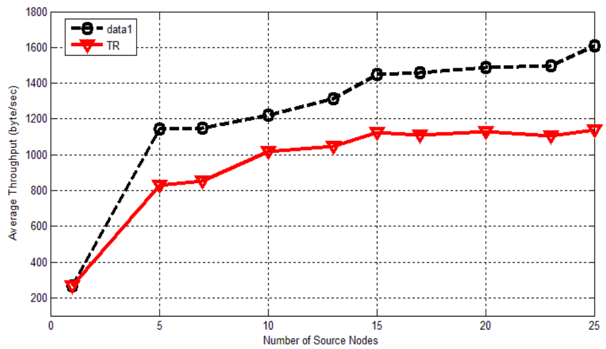

Fig.7 Average throughput (Packets/sec) with different sources.

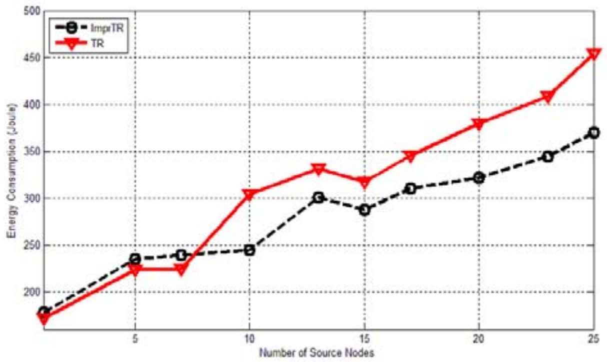

Fig. 8 Energy Consumption (Joule) with different sources.

4. Conclusion

In conclusion the proposed protocol ImpTR has significant overcome the overhead occurred when following the TR protocol because this protocol utilizes the neighbor's node table to find the shortest path toward destination node. The ImpTR improve the routing efficiency of the original TR and there is no need to make any routing discovery. This improvement is translated in to a reduced average end-to-end delay, increase the average throughput and reduce the energy consumption from the network.

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