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A Survey on Routing Protocols in ZigBee Network

Prativa P.Saraswala
Research Scholar at V.T. Patel Dept. of Electronics & Comm. Engg.Charusat, Changa

Abstract---The IEEE 802.15.4 is a new standard defined for LR-WPAN which provides a low cost and very less complicated solution. The targeted applications are wireless sensors networks (WSN), interactive toys, home automation and remote controls. ZigBee is one of the newest technologies developed by ZigBee Alliance, enabling Wireless Personal Area works (WPAN). ZigBee is the name of a specification for a suite of high level communication protocols using small, low-power digital radios based on the IEEE 802.15.4 standard. This paper includes the introduction to Network Nodes and Topology supported by IEEE 802.15.4/ZigBee Standard, also we have discussed the standard routing protocols used in the ZigBee standard. We have done a survey to figure out the variousproposed modified algorithms based on the standard routing protocols, which have better network performance in terms of Packet delivery ratio, Hop delay, Optimal path length, Average end to end delay, Packet loss (%), Network Lifetime, Throughput, Normalized Routing Overhead etc.as compare to standard routing algorithms used in ZigBee network.

Index Terms: **IEEE 802.15.4 standard, LR-WPAN, Routing Protocols, WSN.**

I. INTRODUCTION

The IEEE 802.15.4 is a new standard defined for LR-WPAN which provides a low cost and very less complicated solution. The targeted applications are wireless sensors networks (WSN), interactive toys, home automation and remote controls. ZigBee is one of the newest technologies developed by ZigBee Alliance [1]; enabling Wireless Personal Area works (WPAN). ZigBee is the name of a specification for a suite of high level communication protocols using small, low-power digital radios based on the IEEE 802.15.4 standard. Networking plays a very important role in ZigBee core technologies. There are basically two type routing algorithms used in the ZigBee network AODV and the Tree Based Routing Algorithm. An improved routing algorithm is proposed by analyzing the network topology, configure, formation, address assignment and routing protocol of ZigBee. Here in Section I, we have briefly discussed the Network Nodes and Topology supported by IEEE 802.15.4/ZigBee Standard, Section II includes the explanation of Routing protocols used in the ZigBee network and in Section III, we have presented a survey in a form of table showing the various modified proposed algorithms based on the traditional AODV and the Tree Based Algorithm.

An LR-WPAN [2], [3] is a simple, low-cost communication network that allows wireless connectivity in applications with limited power and relaxed throughput requirements. The main objectives of an LR-WPAN are ease of installation, reliable data transfer, short-range operation, extremely low cost, and a reasonable battery life, while maintaining a simple and flexible protocol. Some of the characteristics of an LR-WPAN are Over-the-air data rates of 250 kb/s, 100kb/s, 40 kb/s, and 20 b/s, Star or peer-to-peer operation, Allocated 16-bit short or 64-bit extended addresses, Optional allocation of guaranteed time slots (GTSs), Carrier sense multiple access with collision avoidance (CSMA-CA) channel access, Fully acknowledged protocol for transfer reliability, Low power consumption, Energy detection (ED), Link quality indication (LQI), 16 channels in the 2450 MHz band, 30 channels in the 915 MHz band, and 3 channels in the 868 MHz band. The new standard targets home and building control, automation, security, consumer electronics, PC peripherals, medical monitoring, and toys. These applications require a technology that offers long battery life, reliability, automatic or semiautomatic installation, the ability to easily add or remove network nodes, signals that can pass through walls and ceilings, and low system cost.

II. NETWORK NODES AND TOPOLOGY SUPPORTED BY IEEE 802.15.4/ZIGBEE STANDARD

ZigBee standard defines three types of nodes [1], coordinator, End Device and Router. A coordinator is a device that works as a heart in a network. PAN coordinator is the one which initializes the network, stores the information of the nodes in the network and also manages the network once it has been initiated. It handles the routing of data to different nodes and suggests what routing techniques to use to transfer the data to different nodes of the network. The Co-coordinator can also provide message routing (for example, in a Star network), security management and other services. There can be only one PAN coordinator in a network; it has the ability to communicate with any device in the network. It can work in all-star, mesh and cluster tree topologies. A router or a Full Functional Device(FFD) supports the data routing functionality, including acting as an intermediate device to link different components of the network and forwarding message between remote

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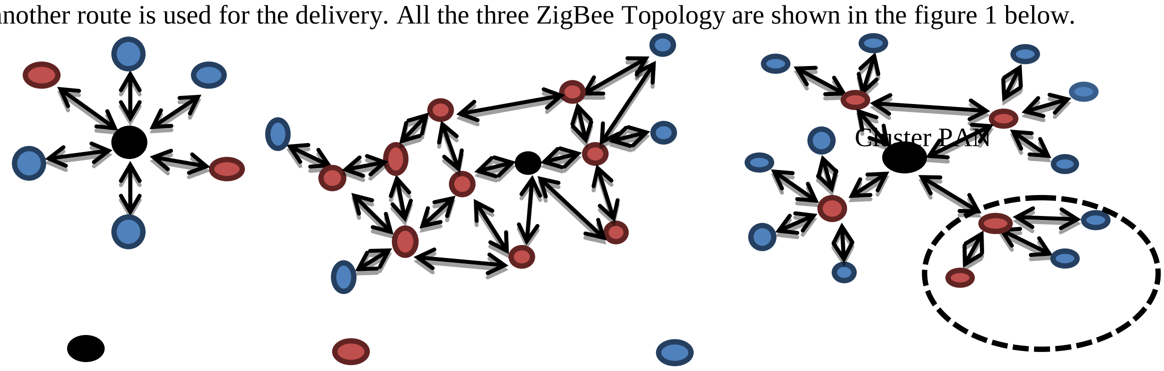
devices across multi hop paths. A router can communicate with other routers and end devices.Routers can be connected to main power supply or run on batteries. Router Networks with Tree or Mesh topologies need at least one Router. In a Star topology, these functions are handled by the Co-coordinator and, therefore, a Star network does not need Routers. In Tree and Mesh topology routers are normally located in network positions that allow messages to be passed up and down the tree. In a Mesh topology, a Router can be located anywhere that a message passing node is required. An end device or Reduced Functional Devices (RFD) is much like a dead end of the network. The main tasks of an End Device at the network level are sending and receiving messages. It cannot relay messages and cannot allow other nodes to connect to the network through them. The RFD has enough functionality to communicate with its parent node: the PAN Coordinator or a Coordinator. An End Device can often be battery-powered and, when not transmitting or receiving, can go to sleep mode in order to conserve power.

On the basis of these nodes types, IEEE 802.15.4/ZigBee supports mainly three types of topology. Star topology, Peer to Peer topology and the Mesh topology. In the star topology a coordinator is responsible for the network. All other devices are end devices and communicate directly with the coordinator. This topology is suitable for networks with a centralized device and for time critical applications. In a peer-to-peer topology, each device can communicate directly with any other device if the devices are placed close enough together to establish a successful communication link. All the devices that participate in relaying the messages are FFDs. One form of peer-to-peer network is a Clustered-*tree* topology, where a PAN coordinator establishes the initial network. Coordinators form the branches and relay the messages. End devices act as leaves of the tree and do not participate in message routing. Coordinator can grow the network beyond the initial network established by the PAN Coordinator.

In Mesh topology, network coordinators are still responsible for the network initiating and maintenance. Routers can be used to extend the network. Routing of data is decentralized in mesh network where the different devices perform the routing in the network. A mesh network is in this way is called self-healing so that if a node fails another route is used for the delivery. All the three ZigBee Topology are shown in the figure 1 below.



Coordinator **Full Functional Devices** **Reduced Functional Devices**

Fig 1: (a) Star Topology (b) Peer to Peer Topology (c) Cluster –Tree Topology [3]

III. ROUTING PROTOCOLS IN ZIGBEE NETWORK

A. Traditional Routing Algorithms

Mainly the Cluster-Tree algorithm [1], [4] and AODV algorithm [5], [6] are used in ZigBee network to reduce cost and power consumption and improve reliability. In a reactive routing protocol, routing paths are searched only when needed. A route discovery operation invokes a route determination procedure. The discovery procedure terminates when either a route has been found or no route is available after examination for all route permutations. AODV determines a route to a destination only when a node wants to send a packet to that destination. Routes are maintained as long as they are needed by the source. Sequence numbers ensure the freshness of routes and guarantee the loop-free routing. AODV uses symmetric links between neighboring nodes. It does not attempt to follow paths between nodes when one of the nodes cannot hear the other one. Nodes do not lie on active paths; they neither maintain any routing information nor participate in any periodic routing table exchanges. When the local connectivity of the mobile node is of interest, each mobile node can become aware of the other nodes in its neighborhood by the use of several techniques, including local (not system wide) broadcasts known as Hello messages.

AODV defines three messages: Route Requests (RREQs), Route Errors (RERRs) and Route Replies (RREPs). These messages are used to discover and maintain routes across the network from source to destination by using UDP packets.AODV is table-driven; routing information for routes in the network is stored in tables. These

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routing tables have the following route entries: destination IP address, DSN, flag, state, network interface, hop count, next hop, the list of precursors and lifetime. Whole process is shown in figure 2 and 3below.

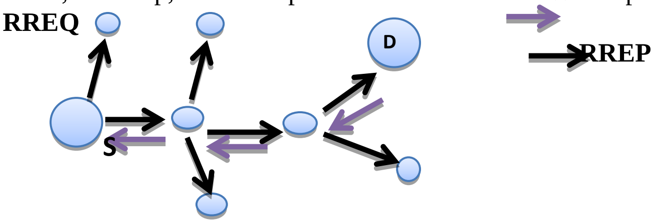

Fig 2: AODV routing protocol with RREQ and RREP message [7]

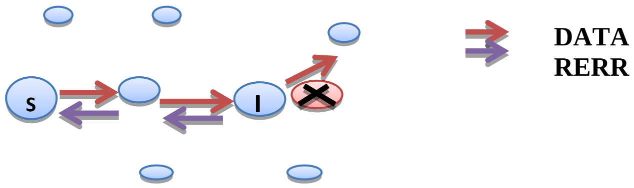

Fig 3: AODV routing protocol with RERR message [7]

B. Cluster tree algorithms [1], [4]

This type of routing is used together with a special method of network nodes addressing. In Tree Routing (TR) protocol, coordinator is responsible to initiate the network by choosing certain key of network parameters and thus becomes the parent node. Other nodes can join the network by becoming the children of theexisting node [10]. In TR protocol, the network addresses are distributed in tree structure in which coordinator useszero network address while other nodes have the non-zero address. The addresses are computed bythe 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)[30]*which is the address block size for each of its router child. For ZigBee routing nodes whose address of A, depth of d, if met the following inequality, then the destination node whose address of D is one of its children:

$A < D < A + Cskip\,(d-1)$ (1)

If it is determined the packet destination node is the descendant of the accept node, the node will send packets to a sub-node. This time, if satisfied:

$D > A + Rm \times Cskip\,(d)$ (2)

It means that the destination node is its terminal child node, then the next node address N as follows:

$N = D$ (3)

Otherwise, if the destination node is not an offspring of receiving node, it will send the packet to its parent node. Example of address assignment is shown in figure 4 below.

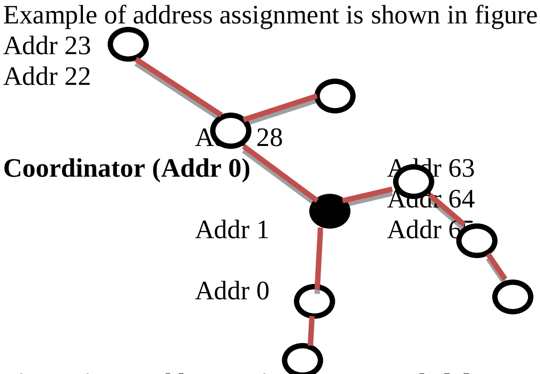

Fig 4: ZigBee address assignment example [4]

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IV. SURVEY ON IMPROVED ROUTING ALGORITHM BASED ON AODV AND CLUSTER-TREE

Before we discuss the different improved routing algorithms over the standard routing protocols used in ZigBee, we will see the quantitative metrics considered for studying the performance of802.15.4. All these metrics are defined with respect to MAC sub layer and PHY layer in order to isolate the effects of MAC and PHY from those of upper layers.

Some of these matrices are:

- **Packet delivery ratio**: The ratio of packets successfully received to packets sent in MAC sub layer. This metric does not differentiate transmissions and retransmissions, and therefore doesn't reflect what percentage of upper layer payload is successfully delivered, although they are related.
- **Hop delay**: The transaction time of passing a packet to a one-hop neighbor, including time of all necessary processing, back off as well as transmission, and averaged over all successful end-to-end transmissions within a simulation run. It is not only used for measuring packet delivery latency, but also used as a negative indicator of the MAC sub layer capacity. The MAC sub layer has to handle the packets one by one and therefore a long delay means small capacity.
- **Optimal path length**: It is the ratio of total forwarding times to the total number of received packets.
- **Average end to end delay**: This is the difference between sending time of a packet and receiving time of a packet. This includes all possible delays caused by buffering during route discovery latency, queuing at the interface queue, retransmission delays at the MAC, and propagation and transfer times.
- **Packet loss (%):** Packet loss is the failure of one or more transmitted packets to arrive at their destination.
- **Media Access Delay**: The time a node takes to access media for starting the packet transmissions called as media access delay. The delay is recorded for each packet when it is sent to the physical layer for the first time.
- **Network Lifetime**: This is defined as the minimum time at which maximum numbers of sensor nodes are dead or shut down during a long run of simulations.
- **Throughput**: It is the number of bits passed through a network in one second. It is the measurement of how fast data can pass through an entity (such as a point or a network).
- **Normalized Routing Overhead:** Routing control number required by sending each data packet. Normalized routing overhead will be better to explain the overhead situation compared to simply using routing overhead. It reflects network congestion degree and node power efficiency. The bigger the protocols overhead, the bigger the network congestion, it will delay packet sending of the interface queue.

Tree based routing and the AODV are the basic algorithms used in the ZigBee network. Based on these two algorithms, Authors have proposed improved algorithm which enhances the existing routing protocols leading to the improvement in the network performance. Figure below presents a list of improved algorithms and its effect on the network performance.

Table I: List of Improved Algorithms and Its Effect on the Network Performance

Traditional Algorithm	**Improved Algorithm over Traditional algorithm**	**Description of Improved Algorithm**
	Improved algorithm uses Cluster-Tree parameter of ZigBee network and network addresses of destination nodes [8].	This combination is used to control the transmission range and restrict its transmission direction. Control overhead is reduced about a half without influencing packet delivery ratio and path length of ZigBee network
	proposed improvements (Fuzzy-Logic based Tree Routing, FL-TR) [9]	Set-up network time and the number of router nodes in the network get reduced, leads in reduction of energy consumed by nodes in the network.
	Self-Learning Routing (SLR) protocol [10]	Because of overhearing and a caching mechanism in SLR, It does not rely on sending any route discovery packets leads to decrease in the end-to-end delay
	Improvement tree routing algorithm, Neighbor Tree Routing (NTR) [11]	It can reduce the network costs and end to end delays, leading to the energy conservation and the real time of the network enhancement.
Tree based Routing	Shortcut tree routing protocol (STR) [12]	It leads to decrease in the routing cost of ZigBee tree routing by using the neighbor table that is originally defined in the ZigBee standard.

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		Simulation results show that the shortcut tree routing algorithm saves more than 30 percent of the hop count compared with ZigBee tree routing.
	Improved Tree Routing (ImpTR) protocol [13]	The new ImpTRprotocol determines the shortest path to the sink node depending on the neighbor table instead of following the tree topology. 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
AODV	ZFA [14] routing protocol based on flooding and AODV	It has higher reliability and lower overhead than AODV
	ARTO-AODV[15]	ARTO-AODV is a dynamic version of AODV i.e. ARTO-AODV.Here active route timeout varies from one second to many seconds. Simulation shows that ARTO-AODV clearly outperforms with respect to packet delivery ratio, throughput, average end to end delay, and energy efficiency.
	EA-AODV [16]	Proposed energy-aware routing mechanism EA-AODV maximizes the use of the limited energy and prolongs the lifetime of ZigBee .The simulation results show that the method about EA-AODV is feasible for saving energy and could improve the performance of ZigBee network.
	AODVLRT (AODV with Local Repair Trials) [17]	Proposed method decreases both of the routing message overhead and the average end to end delay by on average 27.9%, 13.7% respectively less than the well-known AODV routing protocol. This led to increase the throughput by 23.87% more than AODV routing protocol.
	AODV-FL(fuzzy logic)	AODV-FL [18] show a reduction inthe communication delay, number of packets and overhead, improving route efficiency and reducing packet overload.
	Multi-path energy balance routing algorithm (E-AOMDVjr)	Proposed algorithm [19] aims to reduce energy consumption, improve network energy efficiency, and avoid network segmentation and node death. The algorithm can effectively improve the reliability of ZigBee network, and extend the network life.

V. CONCLUSION

The ZigBee network is an emerging field with high practical value. Routing protocol is one of the key technologies of Ad Hoc networks. In this paper, we have discussed the Network nodes and the Topology supported by IEEE 802.15.4/ZigBee Standard and the basic routing protocols used in the ZigBee network. We have done a survey on the proposed modified algorithms based on the existing routing algorithms to improve the network performance.

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AUTHOR BIOGRAPHY

Prativa P.Saraswala is currently working as a Lecturer in Department of Electrical Engg, Maharaja Sayajirao University of Baroda from last three years. She has done her graduation and post-graduation from same University. She is pursuing her PhD from V.T. Patel Dept. of Electronics & Comm. Engg. Charusat, Changa in the field of Wireless Communication.