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IMPACT OF TRANSMISSION POWER ON PERFORMANCE OF ZIGBEE NETWORK BASED ON IEEE 802.15.4 STANDARD USING AODV ROUTING PROTOCOL

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ABSTRACT

Zigbee protocol is based on IEEE 802.15.4 standard which supports low rate wireless personal area network (LR-WPAN). For efficient data transfer and for improved network coverage, Zigbee mostly uses Ad Hoc on Demand Routing protocol called AODV as it is a simple and most efficient. This paper emphasizes on the impact of transmitting power on various performance metrics associated with the Zigbee network such as Packet Delivery Ratio (PDR), Network Throughput and the number of hops. Authors have used TRUE TIME 2.0, a Simulink-based simulator which supports both wired and wireless protocols such as WLAN and IEEE 802.15.4 standard basedZigbee. Based on the simulation done, it can be established that the network through putup swings to a certain range with the increase in transmission power. Packet Delivery Ratio increases with the increase in transmission power due to reduced data packets collision. It can also be observed that the number of hops needed to establish the path between source node and the destination node decreases with the increase in transmission power. Authors have also introduced one more parameter called Hello Interval (HI), associated with the AODV protocol and presented the effect of transmission power on it.Authors have incorporated the concept of energy dissipation taking place at each node while transmission and reception of data message using AODV routing protocol. Energy efficient route concept is useful in prolonging the lifetime of the network.

Keywords: Zigbee protocol, IEEE 802.15.4 standard, LR-WPAN, AODV, WLAN and TRUE TIME 2.0.

1. INTRODUCTION

IEEE 802.11 standard is widely used for high data and high throughout applications but there are several areas where the applications have different set of requirements such as low data rate, limited power capability, less throughput and low cost. For such applications, IEEE developed a new standard known as IEEE 802.154. This standard is called low rate wireless personal area network (LR-WPAN) [1].The expected applications are home/office automation, industrial sensors and its control, wireless sensor network and environment monitoring.

In every system or network, the resources are fixed so it's necessary to manage with the inadequate resources. Routing plays a very important role in the direction of utilizing the limited resources. An intelligent routing strategy can manage with the limited resources as well as it can be adaptable to the changing network conditions like the change in network size, traffic in the network and the network partitioning [2]-[3]. Because of the difficulties of maintaining the list of large neighboring nodes and intimating them regularly about their presence is very difficult in case of huge network, various routing protocols has been proposed for Mobile AdHoc networks. A mobile ad hoc network (MANET) group has been formed within IETF. The primary objective of this group is to develop and advance the MANET specification and solve some of the challenges of Ad Hoc networks such as limited wireless transmission range, hidden terminal problems, packet losses due to transmission errors, mobility- induced route changes, and the battery constraints [4]. Ad Hoc Wireless network has no fixed infrastructure. AdHoc networks are formed on demand and are adaptive to the changes in the network topologies. It is highly dynamic, cost effective and takes less time as compare to cellular network [4]. MANET Routing Protocols are characteristically divided into two main groups: Proactive routing protocols and the Reactive routing protocols which are well explained in [4]. Ad Hoc on Demand Distance Vector routing protocol (AODV) is an example of Reactive routing protocol where a path is established between the source node and the receiver node on demand basis. Zigbee uses AODV routing protocol for the efficient data transfer. There are various performance metrics associated with the Zigbee network such as Packet delivery ratio (PDR), Packet loss ratio (PLR), lifetime of network; end to end delivery time, throughput and hop count as defined in [5]. Apart from these parameters there are other parameters also which effects the performance of Zigbee network such as Transmission power, Receiver signal threshold, Signal transmission range, Path loss exponent, Hello message interval [6]-[7] and Active route time of AODV [6]-[7].

Authors have employed the Zigbee network in TRUE TIME 2.0 in MATLAB using AODV routing mechanism for the performance analysis of Zigbee network. Authors have incorporated the concept of energy utilized during transmission and reception of data at each node. Also, they have presented the effect of transmission power on the performance metrics as discussed above in Zigbee network.

This paper is organized as follows. Section 2 will present the importance of Routing protocol and will also present the related work done by other authors in the direction of performance metric improvement of the Zigbee network using routing techniques. Section 3 will brief the IEEE 802.15.4 standard on which Zigbee protocol is based. Section 4 will comprise the explanation of the system model, developed in TRUE TIME 2.0 in MATLAB and the parameters selected for the simulation of Zigbee network using AODV and the section 5will present the discussion and the conclusions made on the basis of simulation results.

2. RELATED WORK

Authors have done lot of research on the architecture and the routing protocols in Zigbee network. In [8], author has described the fundamentals of Zigbee networking and its reliance upon the mechanism of IEEE 802.15.4 standard. A brief description of Application layer, PHY and MAC properties specified by the IEEE have been distinguished and compared to other common radio protocols available today. The Zigbee network functionality and its use of the IEEE MAC mechanisms for establishing and maintaining the network is explained here. In [9], Author has emphasized on the need of Zigbee protocol, introduction to Zigbee, its benefits and its operation. [10] Presents the inspiration for the Zigbee alliance and includes the explanation of the physical, medium access (MAC) and routing layers of Zigbee network. [11] Presents a brief technical introduction of the IEEE 802.15.4 standard and examines the coexistence influence of an IEEE 802.15.4 network on the IEEE 802.11b devices.

People have done tremendous work on the performance enhancement of Zigbee network by doing performance analysis of various performance metrics associated with the Zigbee network. Zigbee defines two routing protocols: a tree-based routing and the AODV routing mechanism. Because of the simplicity and large coverage area of AODV, it is more popular in Zigbee network for data transmission.

In [12], Authors have improved the AODV based Zigbee routing protocol by using intermediate nodes pivots which leads to a different path as compare to the traditional AODV routing protocol. This methodology leads to the reduction in average end-to-end delay and the average packet loss by 78% and up to 36% respectively. Authors have proposed new routing protocol ZFA which is based on the traditional AODV and the flooding in [13].The proposed ZFA protocol has greater consistency and lesser overhead as compare to traditional AODV.

In the direction of reducing the network control overhead, an improved Zigbee Routing protocol (ZBR) is proposed in [14], where the control overheads becomes almost half without effecting Packet Delivery Ratio and the path length of Zigbee network. Authors have proposed a new routing technique called shortcut tree routing (STR) based on the traditional Zigbee tree routing in [15] which has the advantage of no route discovery overhead and less memory consumption. In [16], authors have accompanied a comprehensive performance of four types of AODV routing protocols in terms of various performance metrics like the packet delivery ratio (PDR), network throughput, normalized routing load and average network delay.

In [17] - [20] authors have proposed several Zigbee mesh routing protocols in order to reduce metrics such as end-to-end delay (EED) and Packet delivery ratio (PDR) by reducing the overhead caused due to route discoveries and Route Requests (RREQs) and also proposed a enhancing method of AODV routing protocol to improve the throughput of Zigbee network.

Authors have done a comparison between AODV and DYMO based non-beacon enabled Zigbee networks in [21].They have considered various performance metrics like Packet delivery ratio, energy consumption and end to end delivery. Simulation shows that the performance of the DYMO outperforms over AODV for Packet delivery ratio and the energy consumption. In order to overcome the problem caused by the tree routing in case of Zigbee network, in [22], Authors have proposed a Shortcut tree routing protocol which decreases the routing cost using existing neighbour table of Zigbee standard. Proposed method saves more than 30% of hop count as compare to traditional tree routing protocol.

Based on the study of the tree routing in Zigbee, Authors have proposed an algorithm called improvement tree routing algorithm (NTR) [23], based on discovering common neighbouring nodes between the source nodes and destination nodes; establishing a strategy on selecting neighbour nodes. Simulation results shows that the NTR reduces the network costs and the end to end delays, leading to the conservation of energy and the network enhancement. In [24] - [27], Authors have emphasized on the impact of transmitting power on various performance metrics such as Packet Delivery Ratio (PDR), throughput, energy consumption and delay overhead, etc.

3. IEEE 802.15.4 STANDARD BASED ZIGBEE NETWORK

IEEE developed new standard known as IEEE 802.154. The expected applications are home/office automation, industrial sensors and control, distributed sensor networks and environment monitoring.Figure-1 presents the architecture of IEEE 802.15.4 standard.

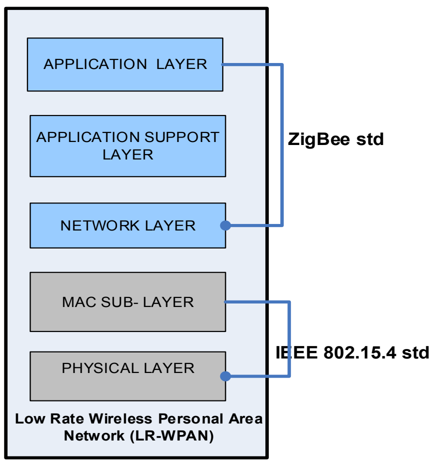

Figure-1. Zigbee stack [1].

The IEEE 802.15.4 standard based stack architecture consist of five layers, MAC and the physical layer is supported by IEEE 802.15.4 standard and the Zigbee stack includes Network layer, Application layer and a security service provider. Application layer consist of three frequency bands offering different data rates. 2.4GHz @ 250kb/s, 868 MHz @ 20 kb/s and 915 @ 40kb/s. This layer is responsible for activation and de-activation of the radio transceiver, transmitting and receiving packets across the physical medium. Energy detection (ED), link quality indicator (LQI), channel selection and clear channel assessment (CCA) [1]. Mac sublayer handles the access to the physical radio channel and take the responsibilities of generation of network coordinator, synchronization to network beacons, providing assistance to personal area network association and disassociation, Employing CSMA-CA(Carrier Sensing Multiple Access- Collision Avoidance) mechanism for channel access [2]. Network layer supports establishment and the maintenance of route between the device nodes, discovering one hop neighbors, providing network configuration, manipulation and the routing of messages.

IEEE 802.15.4 standard mainly supports three types of network topologies. In star topology, Full function devices (FFD) and the Reduced Function Devices (RFD) can directly communicate with the PAN coordinator which manages the whole network. If in case any fault take place, full network become nonfunctional. In case of peer to peer topology, the devices can directly communicate with each other but the PAN coordinator must be there in the network. Third topology is the cluster tree which is a combination of star and the mesh topologies.

4. SYSTEM MODEL

Before talking about the implementation, it is necessary to understand the components of the system. TRUE TIME 2.0 is a MATLAB/Simulink-based simulator which enables co-simulation of controller task execution in real-time kernels, network transmissions and continuous plant dynamics [29]. True Time library contains various blocks like True Time Kernel, True Time Network, True Time Send and Receive and True Time Wireless network etc. [2], [29]. True Time wireless network block is generally used for data transmission in Ad Hoc network. True Time library supports both IEEE 802.11b/g (WLAN) and IEEE 802.15.4 (Zigbee). Zigbee protocol mainly uses CSMA/CA MAC protocol [2], [29] for the data transmission. The TRUETIME blocks are connected with ordinary Simulink blocks to form a real-time control system. Before running the simulation it is necessary to initialize the kernel blocks, blocks related to network selected, create tasks in interrupt handlers, timers, events, monitors etc. for the simulation [29]. AODV defines three types of control messages which are Route Requests (RREQ), Route Replies (RREP) and Route Errors (RERR) used for the route establishment and the invalidating the created route. Whenever a source node needs a route to destination node which is unknown to it, it broadcasts RREQ message to all its neighbor for destination. At each node, when the RREQ is received, a reverse route is established toward the source node. The intermediate nodes which does not have a valid route to the intended destination, it rebroadcasts the RREQ to its neighbors. If the receiving node is the destination or has the route to destination, it generates RREP. As RREP propagates from destination toward source, each intermediate node create a forward route to the destination. Once the RREP reaches to destination, source records the route to the destination and can start sending the message to the destination node.Further information regarding AODV can be obtained from [2]. In order to implement AODV for transmission and reception in True Time, TRUETIME tasks are created in each node. The AODV send task is activated from the application layer and the AODV receive task controls the incoming AODV control messages and the forwarding of data messages. Communication between the application layer and the AODV layer is handled using TRUETIME mailboxes [29]. Flow chart of AODVsend task and AODVrecieve task are shown in Figure-2 and Figure-3 respectively. Here, Authors have tried to show the effect of transmission power on various performance metrics associated with the Zigbee network. Parameters selected is shown in Table-1.

Table-1. Simulation parameters.

Physical layer parameters	
Transmission power (dBm)	-14 to 5
Sensitivity thresholds (dBm)	-48
Path loss exponent	3.5
Area	100x100

MAC layer parameters	
Minimum frame size (bits)	248
ACK timeout (seconds)	0.00004
Retry Transmission limit	5
MAC PROTOCOL	IEEE 802.15.4
MAC layer	CSMA/CA

Network layer parameters	
No. of nodes	30
Data rate	250kbps
Routing protocol	AODV
Hello Interval (seconds)	1
Allowed Hello loss (seconds)	2
Route time	2*Active Route Timeout
No. of packets send	60
Active Route Timeout	3
Delete period	Allowed Hello loss* Hello interval

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Zigbee is based on IEEE 802.15.4 standard which uses Carrier Sense Multiple Access with Collision Avoidance Figure-4 shows the AODV model created in TRUETIME 2.0 for the simulation of AODV routing protocol for Zigbee network.

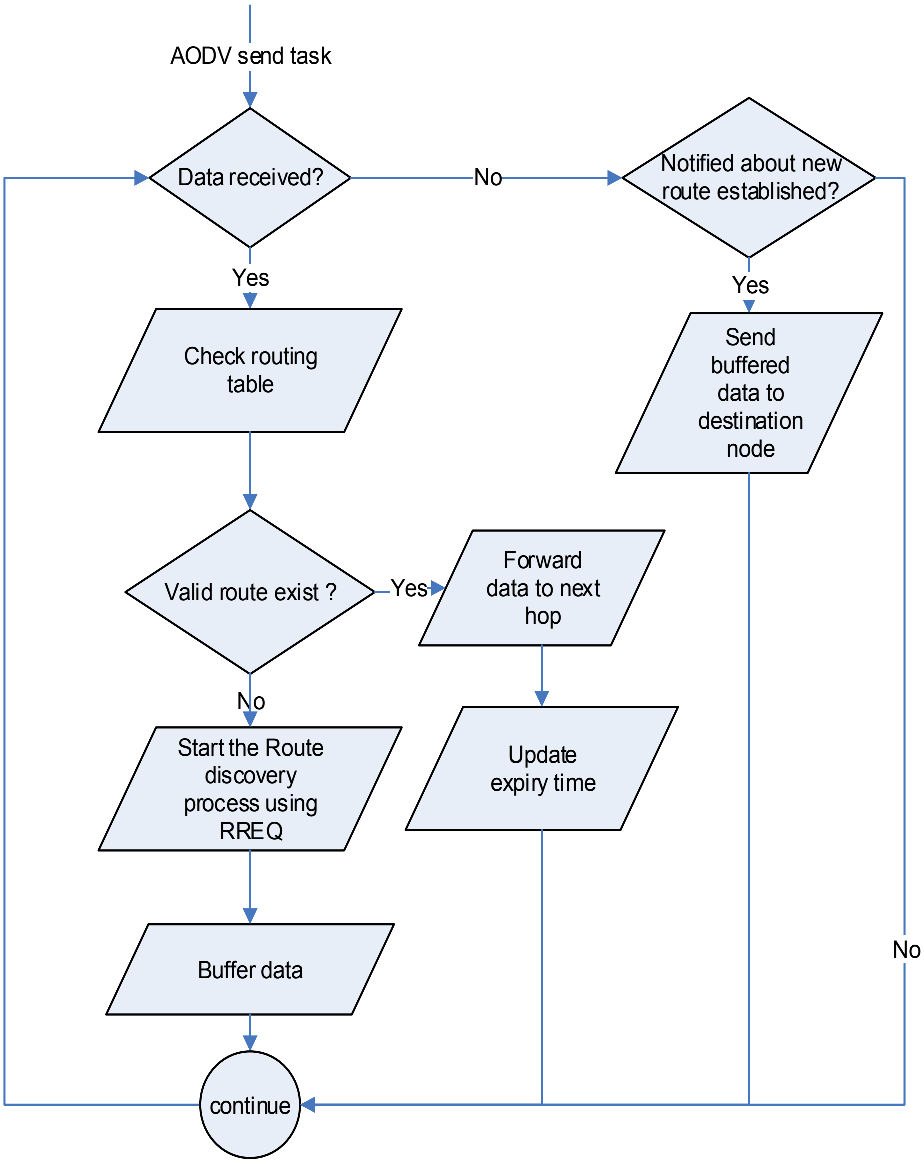

Figure-2. AODVsend task [29].

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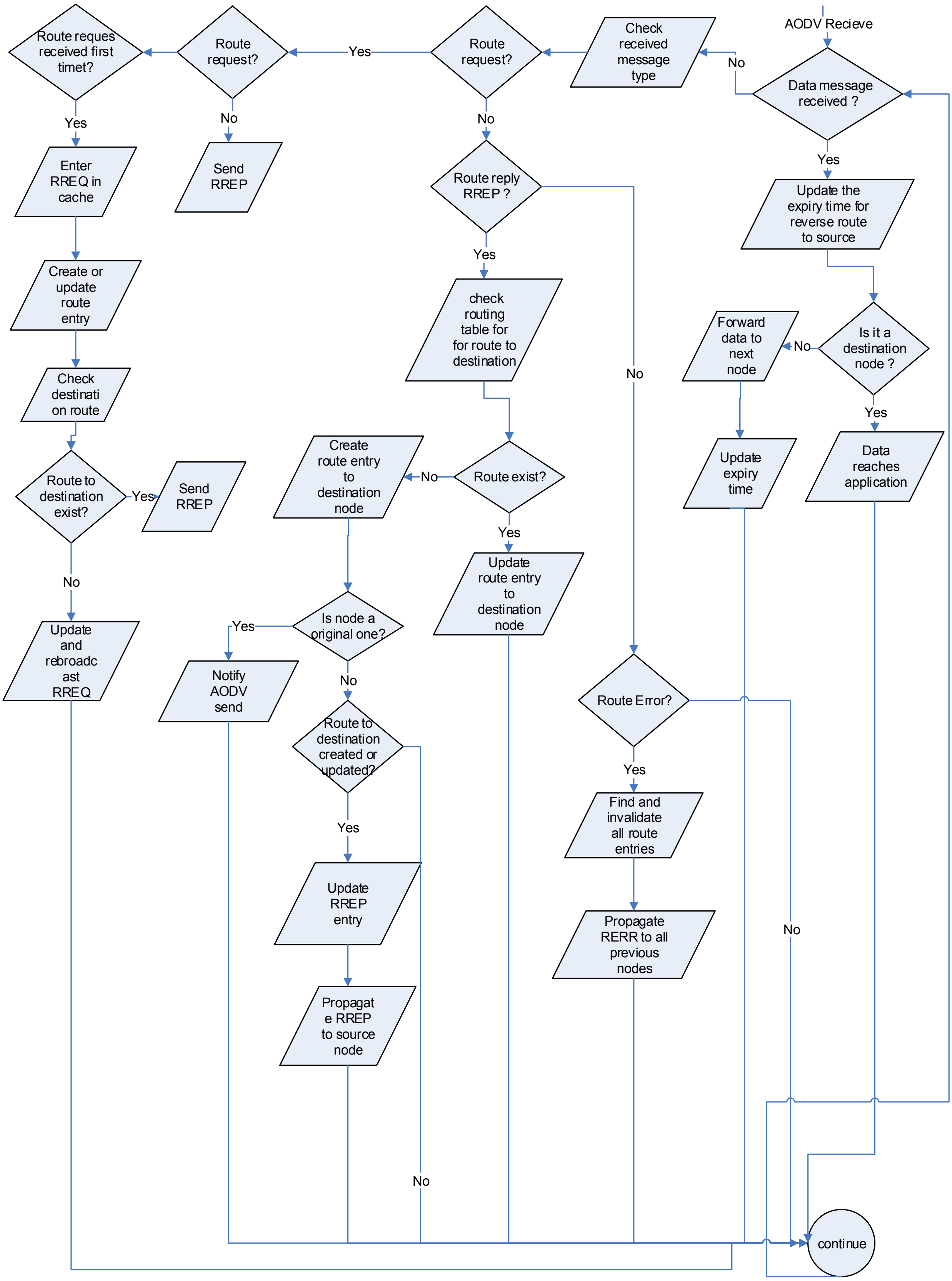

Figure-3. AODV receive task [29].

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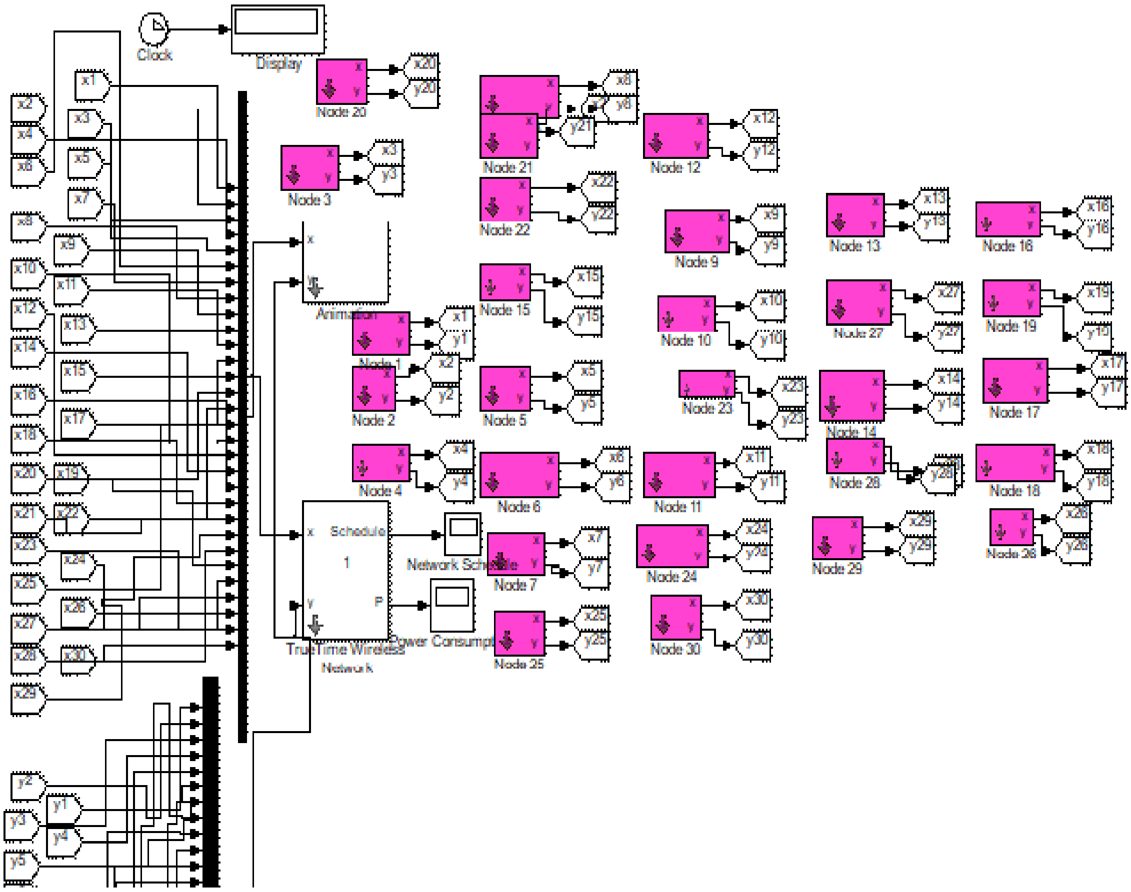

Figure-4. Model generated in TRUETIME 2.0 with 30 nodes.

The network throughput is defined as the total number of bits received by all nodes in the network per second [26]. When the transmission range is relatively small, the link rate dominates the network performance and is increasing with the transmission range. An accepted link rate $r_{link\ rate_{ab}}$ from node a to its neighbour b is given by [26]

$$r_{link\ rate_{ab}}(r) = BW.\log_2(1+\gamma_{ab}) \tag{1}$$

Where BW is the bandwidth of the transrecievers. Required Signal to noise ratio (SINR) γ_{ab} is

$$\gamma_{ab} = \frac{P.G_{ab}}{P_M+\alpha} \tag{2}$$

Where P represents transmitting power at the transmitting node a. P_M is the background noise power level at the receiving node b. G_{ab} shows the link path gain from node a to b. α parameter is assosicated with the spatial resuse [26]. Due to this the network throughput increases with the increase in transmission range, reaches to the maximum and then start decreasing after a certain range.

Authors haveincluded the effect of power dissipated at each node.When a signal is transmitted or received by a node, energy is spent. From the first order radio model [31],[32], the energy dissipated in the process of transmission and reception can be calculated.Equation 4 gives the energy spent by a transmitting node a, transmitting k-bit packet to another node say b placed d meters away from each other.

$$ETX(k,d)=\left(\varepsilon_{elec} + \varepsilon_{amp} \times {d_i}^n\right) \times k \tag{4}$$

and the amount of power spent in receiving k bit packet by node b can be given by equation (5).

$$ETX(k,d)=\varepsilon_{elec} \times k \tag{5}$$

Total energy spent by N number of nodes in the network comprising of eqution (4) and equation (5) for k bit packet size is given in equation (6).

$$E_{total} = \{\sum\left(\varepsilon_{elec} + \varepsilon_{amp \times {d_i}^n}\right) + \varepsilon_{elec}\} \times k \tag{6}$$

Calculation of power plays a very important role in increasing the lifetime of the network.Our idea is to first establish multi routes between the desired source and the destination node. Based on the calculations done with the equations from 4 to 6, energy present at each node can be known. With continous transmission and reception, power will get reduced and may become less than a threshold

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value. A path will get selected having maximum residual energy. This will increase the lifetime of the network. Table 2provides the values of the parameter explained in equation 4 to 6.

Table-2. Parameter selected for system model.

Parameters	Values
ε_{elec}	50nJ/bit
ε_{amp}	10pJ/bit
Path loss exponent n	2
Initial energy of nodes	1J
k (packet size)	4000 bits/round

5. DISCUSSIONS

Based on the explanation given for the throughput in section 4, figure 5 shows the variation of network throughput with the transmitting power and the transmission range. Figure 6 shows the variation of Packet Delivery Ratio (PDR) with the transmitting power. It can be seen that the PDR increases with the increase in transmitting power. As the transmission power increases, collision of data packets reduces which lead to the increase in Packet delivery ratio. Figure-7 shows the relation between transmitting power and the number of hops needed to reach to the destination. It can be witnessed that as the transmitting power reduces, more no. of nodes are needed to establish the path between source node and the destination node so that the successful transmission of data take can take place. With the increase in the transmission radius, the degree of connectivity increases, each node are being able to communicate with more nodes in one hop.

Here one more parameters is added which is associated with the AODV routing protocol called Hello interval (HI), well explained in [6]-[7]. HI get effected by the transmitting power. Hello Interval is used for active neighbour discovery. Each node continously exchanges HI while they are awake. Link failure are very common event that occur in wireless mesh network leading to packet loss and the network unrealiability. To achieve high PDR, link failure need to be fixed. In case of AODV, we found the the link failure can also be decided by Delete period which again depends on HI and the number of missing Hello messages. If the transmitting power of a node is very low then the signal will be very weak and more number of nodes will be needed to reach to the destination node. Also the Hello messages should be sent frequently to know the fast update of neighbourhood change. Figure 8 shows the variation of PDR at three different values of transmitting power at -1dBm, -10dBm and -15dBm. It can be seen that the PDR at -1dBm is more than -10dBm and the -15dBm. For HI equal to 0.5 to 2.5 seconds. The optimum value of HI can lie between 0.5 to 2.5 seconds.

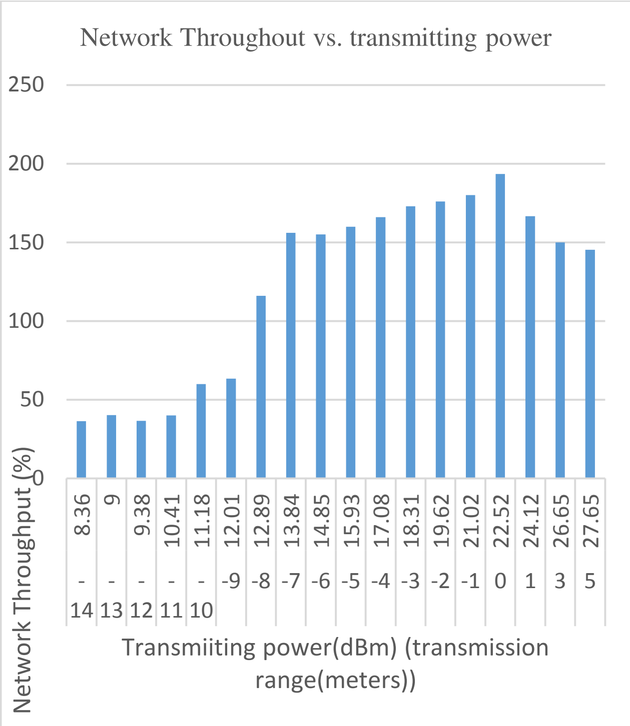

Figure-5. Variation of network throughput vs. transmitting power.

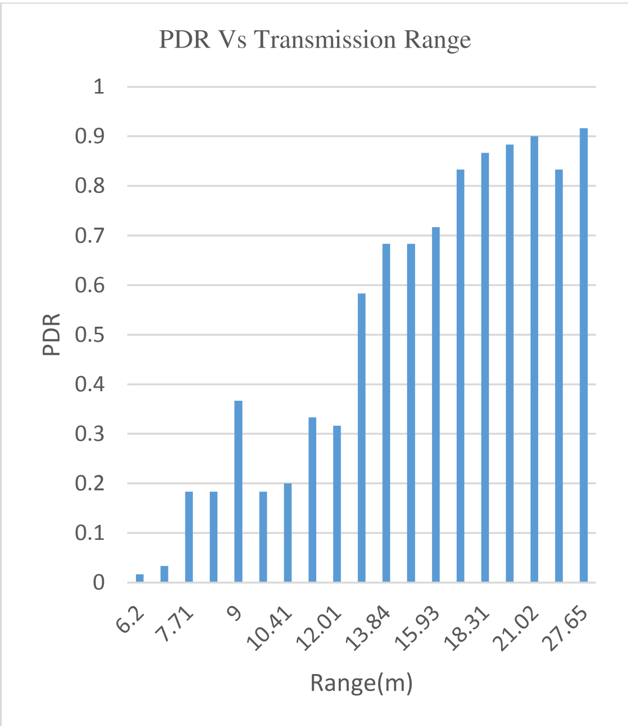

Figure-6. Variation of PDR vs. transmitting power.

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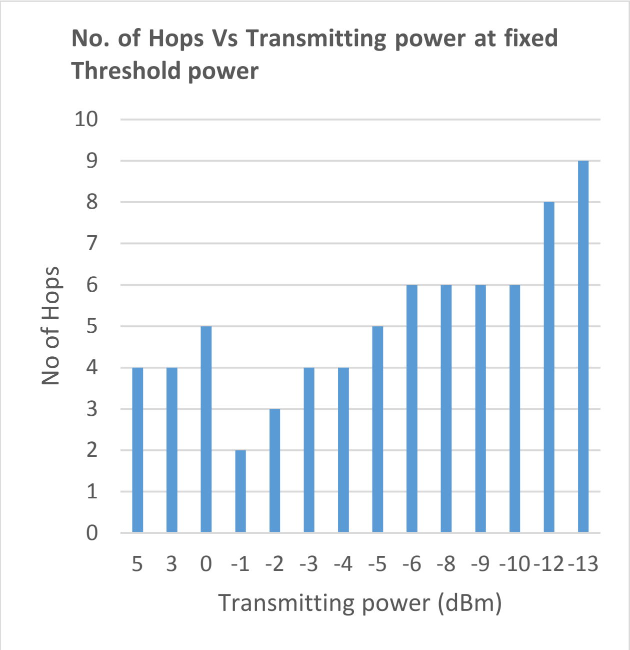

Figure-7. Variation of number of nodes vs. transmitting power.

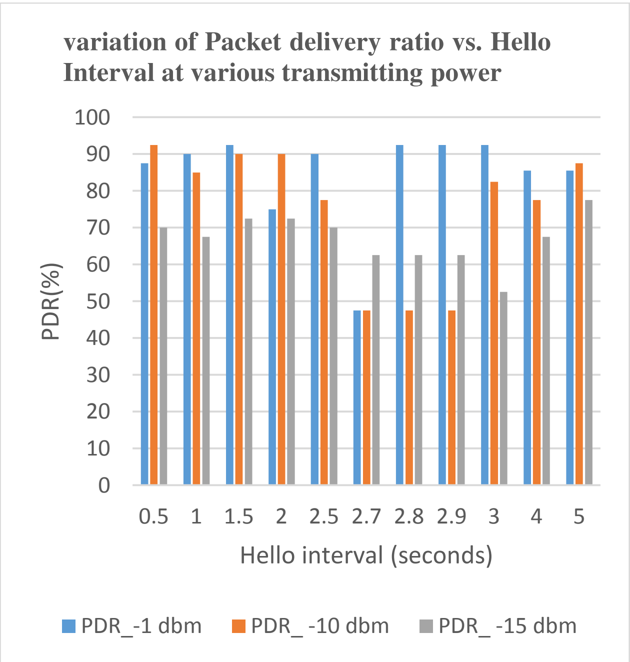

Figure-8. Variation of PDR vs. transmitting power.

6. CONCLUSIONS

Zigbee protocol is based on IEEE 802.15.4 standard which is a low rate wireless personal area network (LR-WPAN) standard. Zigbee protocol supports various routing protocol for efficient data transfer and increased coverage. Ad Hoc on Demand Routing protocol called AODV is mostly used which is a simple and most efficient. There are various performance metrics associated with the Zigbee network such as Packet delivery ratio (PDR), Packet loss ratio (PLR), lifetime of network, end to end delivery time, throughput, hop count and so on. Apart from these parameters, Authors have incorporated few more parameters which effect the performance of Zigbee network such as Transmission power, Receiver signal threshold, Signal transmission range, Path loss exponent and Hello message interval.

Authors have included the effect of power at each node.With the calculation of energyand the knowledge of the residual energyat each node may lead to select an optimum path with longer lifetime.

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