SIMULATION OF WIRELESS SENSOR NETWORK WITH HYBRID TOPOLOGY

J. Jaslin Deva Gifty[1] and K. Sumathi[2]
Department of Electronics and Communication Engineering, Dr. Mahalingam College of Engineering and Technology, India
E-mail: [1]jaslindevaece@gmail.com, [2]sumathimin@gmail.com

Abstract

The design of low rate Wireless Personal Area Network (WPAN) by IEEE 802.15.4 standard has been developed to support lower data rates and low power consuming application. Zigbee Wireless Sensor Network (WSN) works on the network and application layer in IEEE 802.15.4. Zigbee network can be configured in star, tree or mesh topology. The performance varies from topology to topology. The performance parameters such as network lifetime, energy consumption, throughput, delay in data delivery and sensor field coverage area varies depending on the network topology. In this paper, designing of hybrid topology by using two possible combinations such as star-tree and star-mesh is simulated to verify the communication reliability. This approach is to combine all the benefits of two network model. The parameters such as jitter, delay and throughput are measured for these scenarios. Further, MAC parameters impact such as beacon order (BO) and super frame order (SO) for low power consumption and high channel utilization, has been analysed for star, tree and mesh topology in beacon disable mode and beacon enable mode by varying CBR traffic loads.

Keywords:

Wireless Sensor Networks (WSNs), Medium Access Control (MAC) Layer, Beacon Order (BO), Super Frame Order (SO), Qualnet 5.0.2 Simulator

1. INTRODUCTION

The IEEE 802.15.4 is a standard originally designed for Low Rate-Wireless Personal Area Networks (LR-WPANs) for short range communication that provides lower data rate in Kilo bits per second (Kbps). Zigbee Wireless Sensor Network (WSN) is developed on the network and application layer in IEEE 802.15.4 standard. The characteristics of the physical and Medium Access Control (MAC) layers for low power and LR-WPAN is defined by IEEE 802.15.4 protocol and the characteristics of network and application layers is defined by Zigbee wireless sensor network. Zigbee is based on the IEEE 802.15.4 standard for Wireless Personal Area Networks (WPANs) and it is suitable for sensor networks that provide high level communication protocols using small, low-power digital radios. The characteristics of MAC layer deals with the beacon enable and beacon disable mode by varying the Beacon Order (BO) and Superframe Order (SO) parameters for the channel utilization improvement. The formation of WSN topologies depends upon the nodes composition, which transmit data to a sink or server node through point to point links or direct link. In particular, the probability that a node succeeds when accessing the channel to final sink that receives a packet coming from whatever node depend upon MAC layer utilization. When different loads are offered to the network it gives distribution of traffic changes [1]. The three possible topologies such as Star, Mesh and Tree topologies variation depends upon number of hop count. A WSN consists of light-weight, low power and small size sensor nodes (SNs). The SNs has the ability to calculate, monitor and communicate wirelessly. The practical solution for low data rate, low cost and low energy consumption characteristics are offered by Zigbee protocol stack [2]. In ZigBee WSNs, topology has a significant role and is one of the most important parameter in Wireless Sensor Networks. Topology formation process and topology variation parameters related Zigbee analysis is usable to configure Zigbee procedures and in selecting the related parameters of Zigbee Personal Area Network (PAN). The different parameters like throughput, MAC Delay and jitter shows the significant impact on network performance [3]. The various topologies along with MANET routing protocols shows the significant impact on each network that are used for analysis of parameters like throughput, delay and jitter as the performance metrics [4]. The analysis of MAC parameters such as BO and SO for high channel utilization & low power consumption varied for different topology formation. The non-beacon results in better performance [5]. The BO and SO parameters are used to set the duty cycle operation [6]. The structure of each topology is used to analyze and compare the performance metrics [7]. The superframe structure in beacon enable mode is defined by those two parameters [8]. Hybrid topology by using three different possible combinations of schemes of Zigbee routing is considered in different scenarios to certify the communication reliability for the sensor network. Three possible combination Star-tree, Star-mesh and Tree-mesh routing schemes of Zigbee sensor network. It indicates that throughput is valuable in case of star-tree hybrid topology [9]. Wireless sensor is used on health monitoring system There are different standards like Bluetooth and Wi-Fi that works in 2.4GHZ ISM band to support high data rates applications for voice, PC LAN, video etc. However there are so many applications in Industries and Automation, which uses sensors and control devices that do not need high bandwidth but they do need very low energy consumption for long battery life, low latency. Thus, Zigbee sensor network provides standard solutions for automation. It has wide application area such as networking in home and industrial field and having different profiles specified for each field.

The rest of the paper is organized as follows: section 2 addresses the Overview of Physical and MAC layer. In section 3 deals with Network topologies. Simulation and results are dealt in section 4. Conclusions are given in section 5.

2. OVERVIEW OF PHYSICAL AND MAC

The IEEE 802.15.4 standard provides an interface between the PHY radio channel and the MAC layer by the physical layer. The activation and deactivation of radio transceiver done by physical layer from MAC layer according to the request obtained. Energy Detection (ED) within current channel, Link Quality Indication (LIQ) for received packets, channel frequency selection and Clear Channel Assessment (CCA) for Carrier Sense Multiple Access with Collision Avoidance (CSMA-CA) which works in carrier sense, energy above threshold and carrier sense with energy above threshold mode. The selection of radio type, transmission power (dBm), packet reception model, modulation scheme are available in physical layer. It supports unlicensed industrial scientific medical (ISM) frequency bands of 2.4 GHz and also two PHY options based on the frequency band of 868/915 MHz, both of them are based on Direct Sequence Spread Spectrum (DSSS). The MAC layer of Zigbee employs the channel access mechanism using CSMA-CA algorithm and provides secure message transmission over single hop communication, device type (FFD & RFD), Poll interval, Superframe Order (SO) and Beacon Order (BO). The IEEE 802.15.4 supports two different physical devices such as Full-Function Device (FFD) and Reduced-Function Device (RFD).

2.1 FULL-FUNCTION DEVICE (FFD)

2.1.1 PAN Coordinator/Zigbee Coordinator (ZC):

In first mode, FFD act as PAN coordinator or Zigbee coordinator. It is the central controlling device of the network. It acts as a gateway to other networks. It might be in beacon-enabled mode or beacon-disabled mode. All Zigbee networks must have one central PAN Co-ordinator and it starts the network and synchronizes all the devices in the network by transmitting beacons periodically frame during beacon-enable mode.

2.1.2 Coordinator/Zigbee Router (ZR):

In second mode, FFD act as Coordinator or Zigbee router and relay messages to end devices. It acts as intermediate device and supports data routing across multi-hop path between remote devices. It can communicate to other FFDs or RFDs.

2.1.3 Zigbee Device (ZD):

In third mode, FFD act as a device that does not relay the messages and it is low powered battery device.

2.2 REDUCED-FUNCTION DEVICE (RFD)

RFD also called as Zigbee End terminal Device (ZED). They can only communicate with its parent node, the PAN coordinator or coordinator. It does not have data routing functionality to relay messages to other end devices but can establish connection with FFDs (PAN coordinator or coordinator) and communication to other RFDs only through FFDs. The IEEE 802.15.4 MAC layer mechanism is based on CSMA/CA protocol. It supports two modes of operation Beacon enabled and Beaconless-enabled mode.

2.3 BEACON ENABLED MODE

A Zigbee PAN coordinator which is the central node of all Zigbee networks periodically generates beacon frame that provides synchronization and slots to RFDs device for data transmission. The beacon enabled mode defines the periods of time to occur transmissions and intervals of time where all nodes associated to it must go to sleep by using slotted CSMA-CA mechanism. Beacon enable mode is defined by a super frame structure.

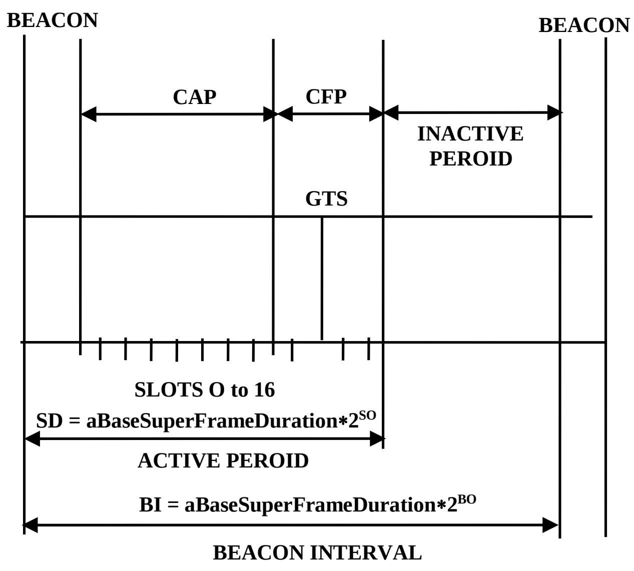


Fig.1. Superframe structure of IEEE 802.15.4

The active period consists of time slots (0 to 16) is sub divided into two period such as contention access period (CAP) and contention free period (CFP) that allows Guarantee Time Slot (GTS) mechanism. At 0 slots, the PAN coordinator transmits beacon signals after the completion of beacon CAP and further it uses CSMA/CA algorithm. The FFDs can ask for guaranteed time slot (GTS) that provides the fixed rate of transmission from the coordinator. The Beacon Interval (BI) and the Super frame Duration (SD) are determined by two parameters such as the Beacon Order (BO) and the Super frame Order (SO). The SO and BO should satisfy the relationship $0 \leq SO \leq BO \leq 14$ for beacon enable mode.

2.4 NON-BEACON ENABLED MODE

In beacon enabled mode, it uses unslotted CSMA/CA and does not provide synchronization and guarantee time to RFDs devices which send their data to sink node or server node. A node can transmit and sleep at any time, following its own energy consumption policy. To disable it must satisfy this relation SO = BO = 15.

3. NETWORK TOPOLOGY

A Zigbee network can adopt three types of network topology: Star, Mesh and Tree topology.

3.1 STAR TOPOLOGY

A Star network shown in Fig.2 consists of PAN coordinator which is the central node and set of end devices RFDs or FFDs. Each End Device can communicate only with the Coordinator. The message must be sent via the router or coordinator from one end terminal devices to other to reach the destination. Single hop transmissions are in this case sufficient for communication.

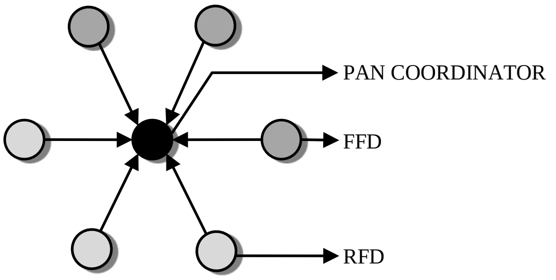


Fig.2. Star network

3.2 TREE TOPOLOGY

A Tree network shown in Fig.3 has a top node which is the sink node with a branch/leaf structure below. The PAN Coordinator is the top (root) node in the network. This can continue to a number of levels to reach its destination, a message travels up the tree or down the tree.

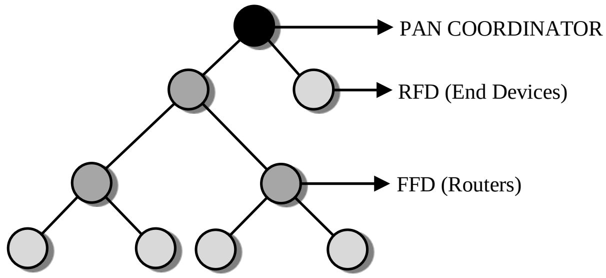


Fig.3. Tree network

3.3 MESH TOPOLOGY

A Mesh network shown in Fig.4 is similar to tree-like structure shown in Fig 4 in which some leaves that is the coordinator devices are directly linked or point to point connected. In mesh topology, communication took place with any neighbor and the structure being decentralized.

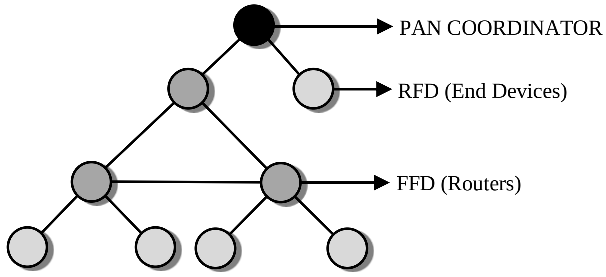


Fig.4. Mesh network

4. SIMULATION AND RESULTS

The star,tree and mesh topology is considered with 15 nodes. In star topology , the nodes are connected to the central PAN coordinator. In tree, the nodes are connected in uplink direction to PAN coordinator through FFDs devices which act as coordinator and in mesh topology, the similar setup is made as like tree topology but the coordinator devices are point-to-point connected to form mesh connection. The simulation is carried out by varying SO and BO order. First the simulation is carried out by setting the order SO = BO =3 (beacon enable mode) and by setting the order SO = BO = 15 (beacon disable mode). The average jitter, average end to end delay and throughput is calculated and compared for the order 3 and 15. The mathematical proof as follows. The low power operation for network is achieved by choosing low duty cycle or to disable beacon order by assigning the value as 15. The duty cycle is calculated as,

$$\text{Duty cycle} = 2^{SO-BO} \times 100\%.$$

Therefore, each device will be active for 2^{SO-BO} portion of time, and sleep for $1-2^{SO-BO}$ portion of time. The SO parameter should be low value when compared to BO to have active and inactive period. When both parameters are taken as the same order there will be absence of inactive period hence consumes large power consumption. A large duty cycle result in higher power consumption as devices remains in active state for longer periods and there will absence of inactive period. In this simulation the parameter SO and BO is taken as 3, hence $2^{3-3} \times 100$. The result shows absence of inactive period and high power consumption. The simulation is performed with the following parameters mentioned in Table.1.

Table.1. Simulation Parameters

Parameters	**Values**	**Hybrid topology values**
Area	500m*500m	500m*500m
Topology	Star, Tree, Mesh	Star-tree, Star-mesh
Simulation Time	300sec	300sec
Item to send	100	100
Packet size	60bytes	60bytes
Packet rate (packet per sec)	0.1.0.2,1,2	1,2,3,4,6
MAC layer	802.15.4	802.15.4
Energy Model	Mica motes	Mica motes
Battery Model	Linear model	Linear model
Protocol	AODV	AODV
BO,SO	3,15	15
No of nodes	15	20,40,60
Traffic	CBR	CBR

4.1 AVERAGE JITTER

Average jitter versus packet interval is shown in Fig.5, Fig.6 and in Fig.7 for Star, Tree and Mesh network. In star network for beacon disable mode when the order is 15, it shows lower jitter for all packet intervals compared to beacon enable mode when the order is 3. It is due to the single-hop communication for star network. In tree network, the jitter value is randomly increasing and decreasing and in mesh network its shows higher jitter value for all packet intervals due to the multi-hop communication.

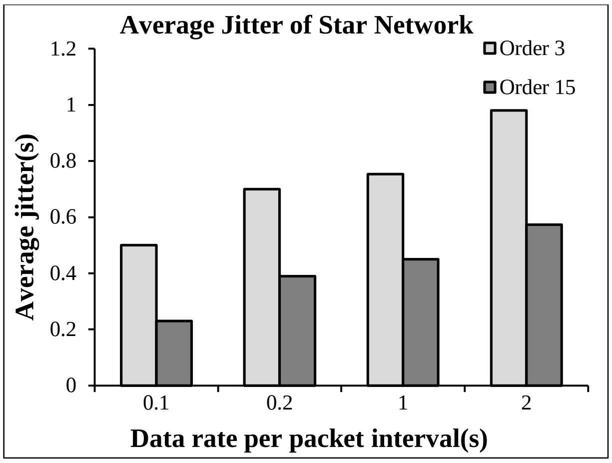


Fig.5. Star network

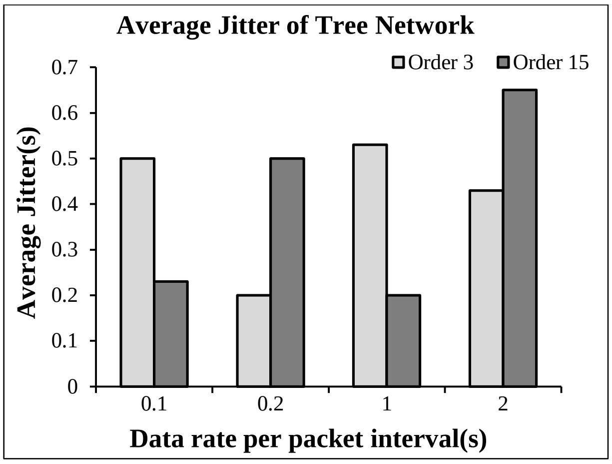


Fig.6. Tree network

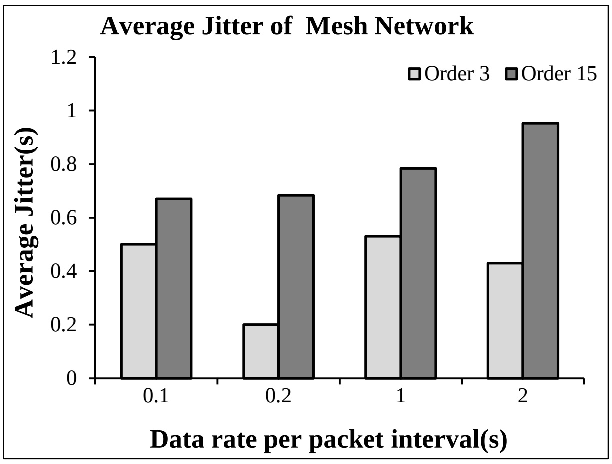


Fig.7. Mesh network

4.2 AVERAGE END TO END DELAY

Average end to end delay versus packet interval is shown in Fig.8, Fig.9 and in Fig.10 for Star, Tree and Mesh network. In star for beacon disable mode, it shows lower delay for all packet interval when compare to beacon enable mode. But in case of tree and mesh network it shows high delay for all packet intervals for beacon disable mode. Though the higher delay may due to multi-hop communication in both tree and mesh network.

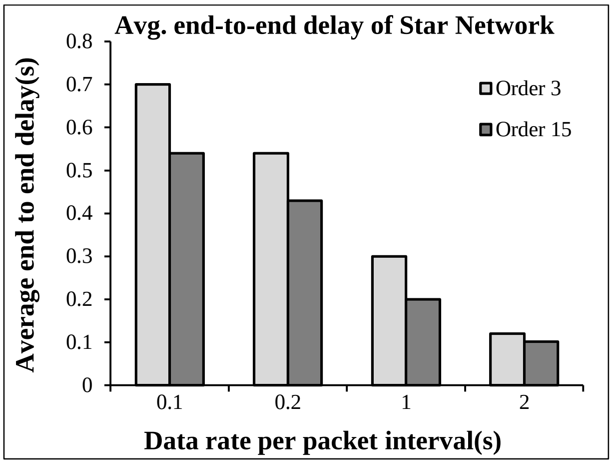


Fig.8. Star network

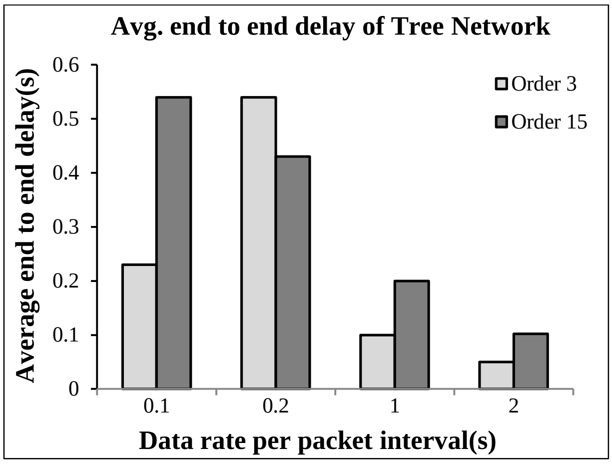


Fig.9. Tree network

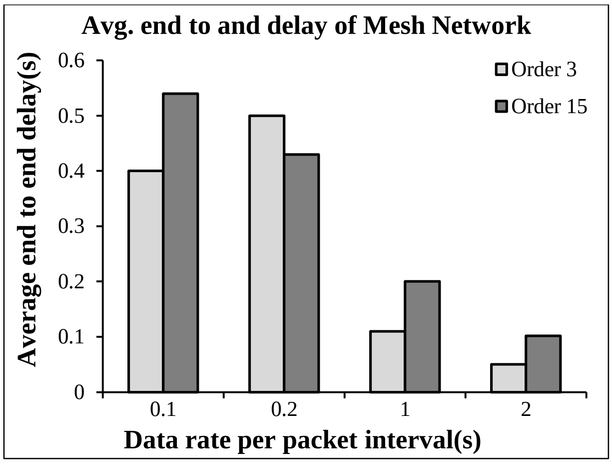


Fig.10. Mesh network

4.3 THROUGHPUT

Throughput versus packet interval is shown in Fig.11, Fig.12 and in Fig.13 for Star, Tree and Mesh network. In star, tree and mesh network, it shows higher throughput for beacon disable mode when compare to beacon enable mode. The absence of beacon frame collision is the reason of achieving higher throughput in all three networks. The higher throughput results in better performance of the network.

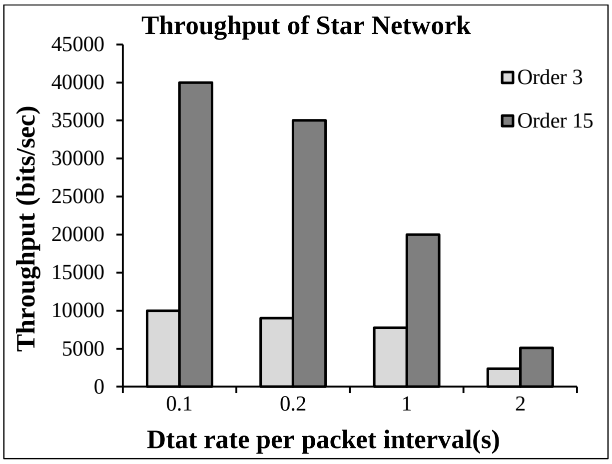


Fig.11. Star network

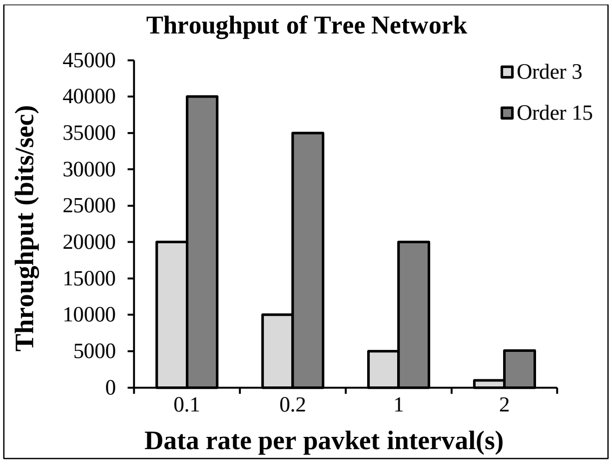


Fig.12. Tree network

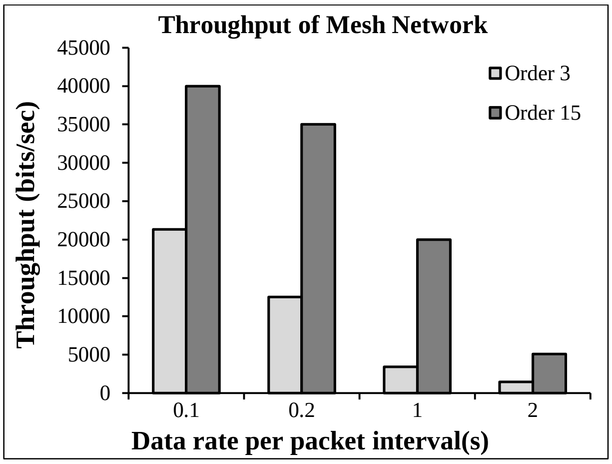


Fig.13. Mesh network

4.4 ENERGY CONSUMPTION IN TRANSMIT AND RECEIVE MODE

The energy consumption in transmit mode and receive mode versus packet interval is shown in Fig.14 and Fig.15 for order 3 (Beacon enable mode) and 15 (Beacon disable mode). Its shows low energy consumption in all data rate per packet interval for star, tree and mesh network for beacon disable mode.

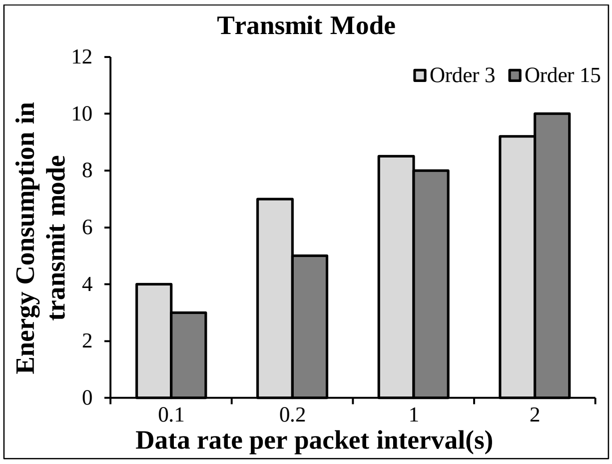


Fig.14. Transmit mode

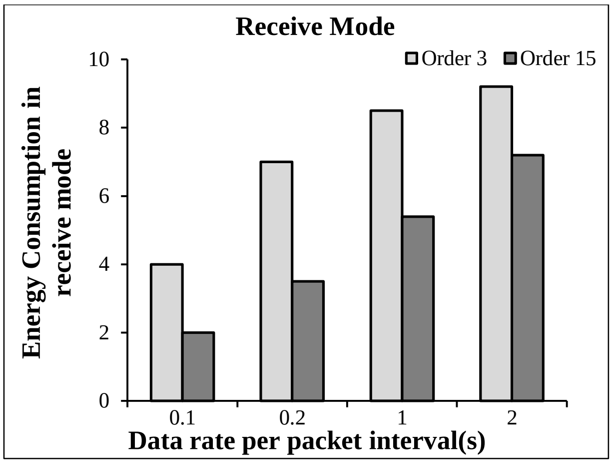
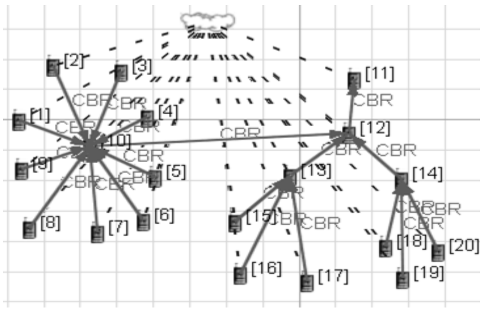


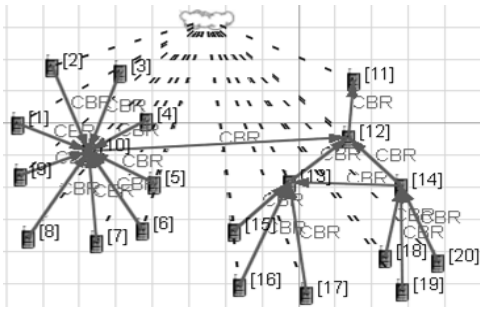
Fig.15. Receive mode

4.5 HYBRID TOPOLOGY

The hybrid combination for star-tree and star-mesh with 20 nodes is considered shown in Fig.16.

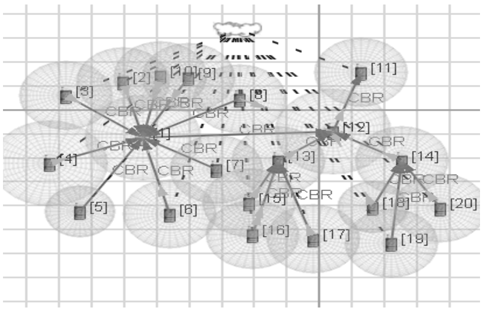


(a)

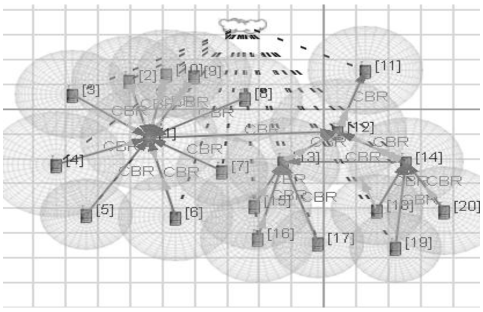


(b)

Fig.16. (a). Star-Tree network (b). Star-Mesh network



(a)



(b)

Fig.17. Run-time scenario for (a). Star-Tree network (b). Star-Mesh network

The run time scenario for Star-Tree and Star-Mesh network is shown in Fig.17. Each scenario consists of same number of FFDs, RFDs and two PAN co-ordinator devices to construct hybrid combinations. The simulation is carried out for Star-Tree and Star-Mesh by increasing the node densities to verify the performance of two combined topologies. The average jitter, average end to end delay and throughput is calculated and compared for those two combinations. The result shows it performs better in star-tree combinations when compared to star-mesh. The simulation is performed with the following parameters mentioned in Table.1.

4.5.1 Average Jitter:

Average jitter versus packet interval is shown in Fig.18, Fig.19, Fig.20 for Star-tree and for Star-mesh network with 20, 40, 60 nodes.

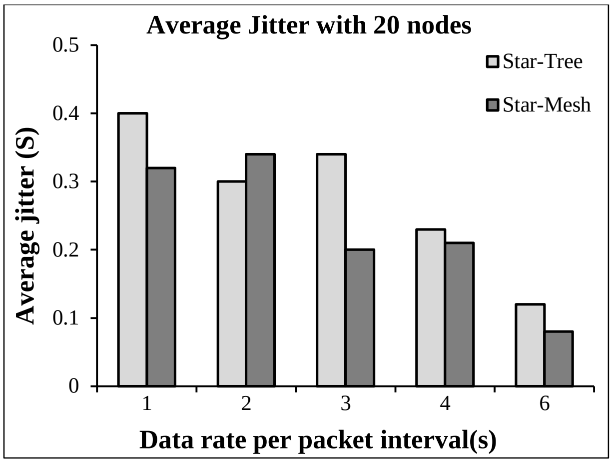


Fig.18. Average jitter for 20 nodes

The jitter is low for all packet intervals in case of Star-tree network and it also shows lower jitter value in Fig.19 for Star-tree when compared to Star-mesh network even when the node density increases to 40 and 60. Lower jitter results in better performance of the network.

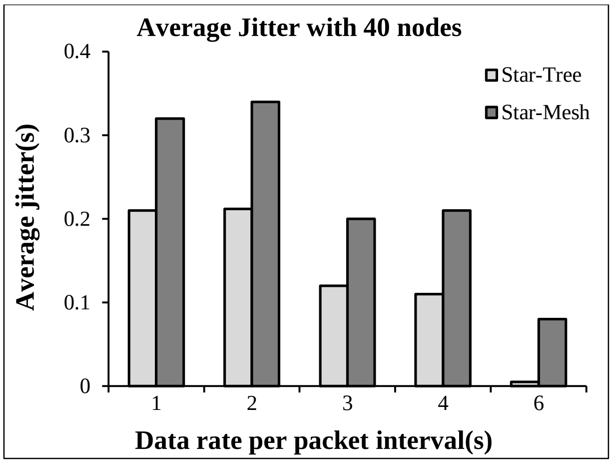


Fig.19. Average jitter for 40 nodes

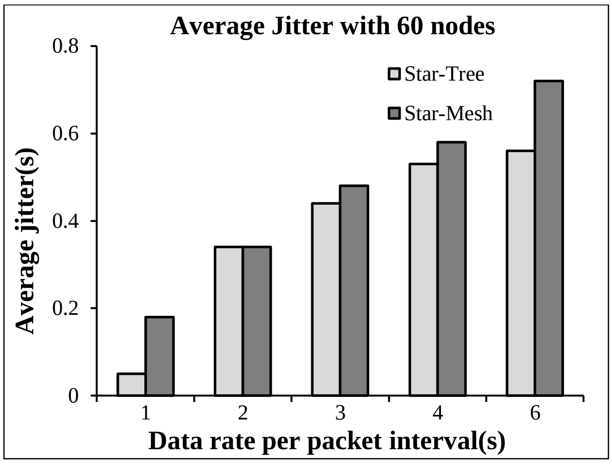


Fig.20. Average jitter for 60 nodes

4.5.2 Average End to End Delay:

Average end to end delay versus packet interval is shown in Fig.21, Fig.22, Fig.23 for Star-tree and Star-mesh network with 20, 40, 60 nodes. The delay is low for all packet intervals in case of Star-tree network and it is also shows lower delay value in Fig.22 for Star-tree when compared to Star-mesh network even when the node density increases to 40 and 60. Lower delay results in better performance of the network.

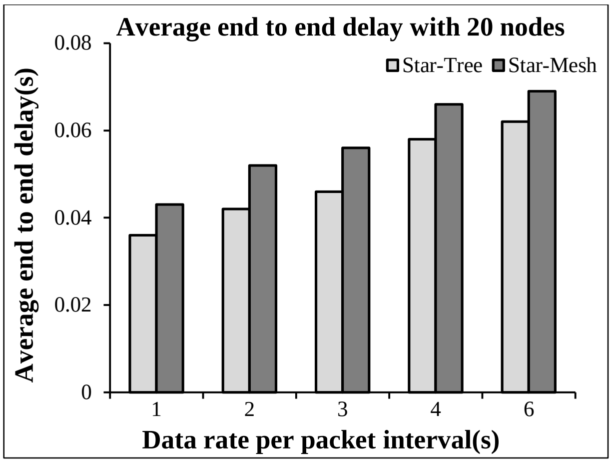


Fig.21. Average end to end delay for 20 nodes

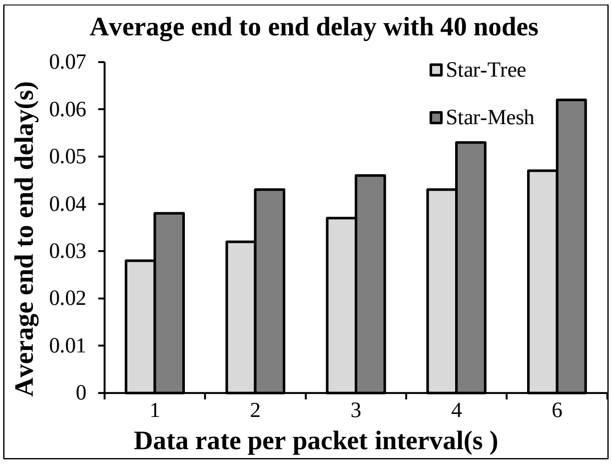


Fig.22. Average end to end delay for 40 nodes

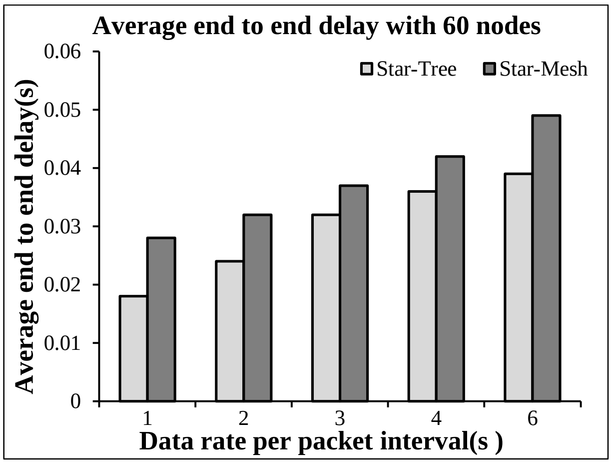


Fig.23. Average end to end delay for 60 nodes

4.5.3 Throughput:

Throughput versus packet interval is shown in Fig.24, Fig.25, Fig.26 for Star-tree and for Star-mesh network with 20, 40, 60 nodes. The throughput is high for all packet intervals in case of Star-tree network and it is also shows higher throughput value in Fig.25 for Star-tree when compared to Star-mesh network even when the node density increases to 40 and 60. Higher throughput results in better performance of the network.

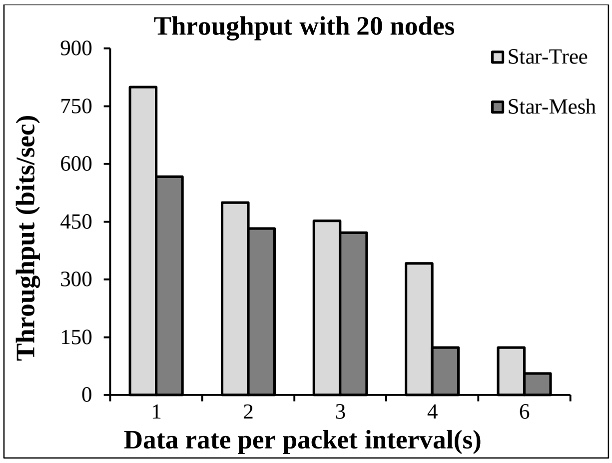


Fig.24. Throughput for 20 nodes

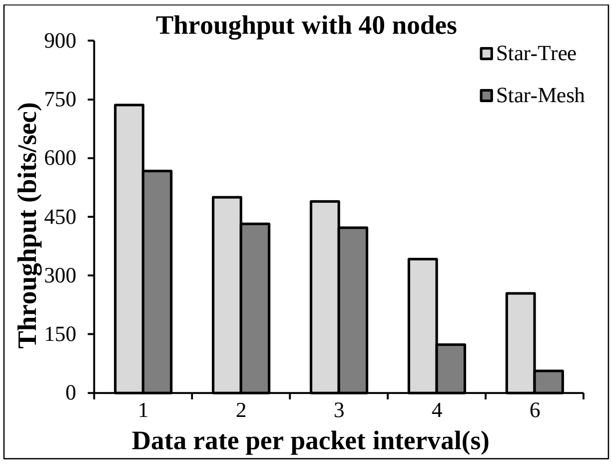


Fig.25. Throughput for 40 nodes

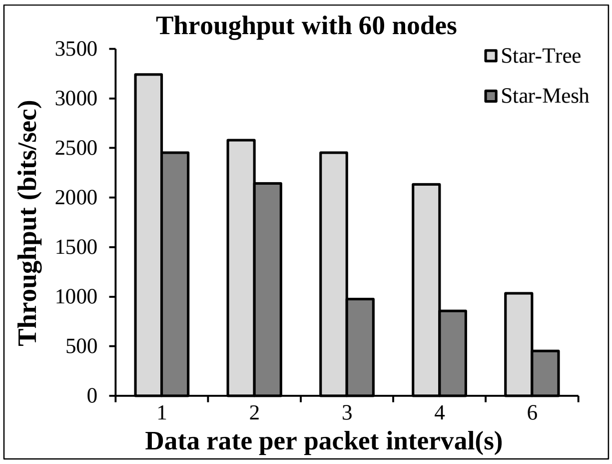


Fig.26. Throughput for 60 nodes

5. CONCLUSION

The result shows the impact of MAC parameters performance of Beacon order (BO) and super frame order (SO) on IEEE 802.15.4 for star, tree and mesh network for the improvement of low power consumption and channel utilization. Various performance metrics have been analyzed with different traffic loads for ad-hoc on demand distance vector routing protocol. Beacon disable mode performance is better compared with non beacon mode for all topologies. It shows that the beacon disable mode performs better in star, tree and meshes topologies and has low energy consumption. The demand of low power consumption by sensor nodes achieved in beacon disable mode. Further, the hybrid combination of star-tree network and star-mesh network is compared to analyze the performance metrics such as jitter, delay and throughput. It shows better performance achieved in star-tree network combination when compared to star-mesh network.

REFERENCES

[1] Chiara Burratti and Roberto Verdone, "Performance Analysis of IEEE 802.15.4 Non-Beacon Enabled Mode", *IEEE Transactions on Vehicular Technology*, Vol. 58, No. 7, pp. 3480-3493, 2009.

[2] Shubhanshi Rathore, Rajeev Paulus, A.K. Jaiswal and Aditi Agarwal, "Analysis of QOS and Energy Consumption in IEEE 802.15.4/ZigBee Wireless Sensor Network", *International Journal of Computer Applications*, Vol. 121, No. 17, pp. 40-43, 2015.

[3] Lovish Jaiswal, Jaswinder Kaur and Gurjeevan Singh, "Performance Analysis of Topological Variation in Personal Area Network using ZigBee Wireless Sensors", *International Journal of Computer Science and Technology*, Vol. 3, No. 4, pp. 706-711, 2012.

[4] M.M. Chandane, S.G. Bhirud and S.V. Bonde, "Performance Analysis of IEEE 802.15.4", *International Journal of Computer Applications*, Vol. 40, No. 5, pp. 23-29, 2012.

[5] Reema Garg, Rajeev Paulus, A.K. Jaiswal and A. Ashok, "Performance Analysis of a Beacon and Non Beacon Enabled IEEE 802.15.4 Star WSNs with Different Traffic Loads", *International Journal of Current Engineering and Technology*, Vol. 4, No. 2, pp. 987-992, 2014.

[6] Sarvesh Kumar Singh, Rajeev Paulus, A.K. Jaiswal and Mayur Kumar, "Analysis of Energy Model and Performance of IEEE 802.15.4 WSNs under Different Duty Cycle", *IOSR Journal of Electronics and Communication Engineering*, Vol. 9, No. 2, pp. 48-54, 2014.

[7] Boris Mihajlov and Mitko Bogdanoski, "Overview and Analysis of the Performances of ZigBee based Wireless Sensor Networks", *International Journal of Computer Applications*, Vol. 29, No.12, pp. 28-35, 2011.

[8] Chiara Burratti, "Performance Analysis of IEEE 802.15.4 Beacon Enabled Mode", *IEEE Transactions on Vehicular Technology*, Vol. 59, No. 4, pp. 2031-2045, 2010.

[9] Amritpal Kaur, Jaswinder Kaur and Gurjeevan Singh, "An Efficient Hybrid Topology Construction in Zigbee Sensor Network", *Proceedings of IEEE International Conference on Recent Advances and Innovations in Engineering*, pp. 1-6, 2014.

[10] Muneer Bani Yassein, Mohammad Hamdan, Hisham and Lina Mrayan, "An Improvement on Health Monitoring System for Multiple Patients Using Wireless Sensor Network", *MAGNT Research Report*, Vol. 3, No. 7, pp. 1-15, 2015.