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Research Article

Performance Analysis of a Beacon and Non Beacon Enabled IEEE 802.15.4 Star WSNs with Different Traffic Loads

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Abstract

This paper deals with IEEE 802.15.4 beacon enabled and non beacon enabled multi-hop star wireless sensor networks with varying traffic loads. For high channel utilization & low power consumption, impact of MAC parameters such as beacon order (BO) and superframe order (SO) has been analyzed. IEEE 802.1.5.4 MAC works in two modes, beacon and non beacon mode. This paper provides the performance analysis of IEEE 802.15.4 star topology using DYMO protocol by dynamically adjusting the BO and SO values depending on the traffic loads. Various network performance parameters calculated are throughput, average end to end delay, average jitter, total energy consumption, percentage of time in sleep mode, residual battery consumption. Simulation is performed on a Qualnet Simulator version 6.1. The comparative analysis of result shows that it can be concluded that performance of DYMO is better in non beacon enabled mode. For low values of data rates, network performance parameters are better for all BO and SO.

Keywords: *Beacon order, IEEE 802.15.4, Medium access control (MAC), Qualnet 6.1, Superframe order, WSN.*

1. Introduction

Wireless sensor network consists of a hundreds and thousands of low cost, low power, multifunctional sensors called nodes with excellent amount of sensing capabilities. In present scenario, wireless technology has become essential in each and every field such as personal health care, industrial applications, telecom services, home automation, surveillance, tracking, environment monitoring, search & rescue etc (I.F.Akyildiz *et al*, 2002). Due to the rapid growth in wireless technology, one of the methods mainly preferred for wireless communication is IEEE standard 802.11 (Wireless LAN). It has several advantages but mainly concerned with high data rate and supports long range applications. The development of a variety of devices such as PC & peripherals, laptops, tablets, mobile phones, consumer electronics, toys & games have demanded for short range, low cost and low power wireless standard. So the best method preferred is IEEE 802.15 (WPAN). It is specifically designed to provide low cost, low power, short range wireless networks (Jennifer Yick *et al*, 2008). IEEE 802.15 wireless personal area network working group is classified into four task group WPAN/Bluetooth (IEEE 802.15.1), coexistence (IEEE 802.15.2), WPAN high rate (IEEE 802.15.3), WPAN low rate (IEEE 802.15.4). Bluetooth is a short range radio technology that supports medium data rate of 1 Mbps and used for authentication, encryption and voice applications. IEEE 802.15.2 developed a coexistence model and mechanisms document. WPAN (802.15.3) supports high data rate of 55 Mbps and has fast join multi-media features. For wireless sensor networks, low rate WPAN (802.15.4) was designed for supporting various short range applications in a cost effective way. LR-WPANs has data rate up to 250 kbps and its battery life is also from multi- month to infinite.

So, the IEEE 802.15.4 protocol has been proposed as a wireless communication standard for low rate, low power consumption wireless personal area network (LR-WPANs). Zigbee is an open specification for low power wireless networking built on the IEEE 802.15.4 physical and MAC layer standard. Zigbee has been emerged as an effective alternative for WPANs supporting various short range applications like disaster relief recovery, habitat monitoring, battlefield monitoring, home automation, tracking, surveillance, medical health care etc, accident detection, precise agriculture, traffic monitoring and many other (Andrew Wheeler *et al*, 2007). The LR-WPAN or IEEE 802.15.4 is described in detail in next sections. In this paper, performance of IEEE 802.15.4 star network by varying MAC parameters under different traffic loads has been analyzed.

Section II discussed related works for the performance evaluation of WSN. Section III gives the overview of IEEE 802.15.4 protocols. Section IV explained the simulation set up and performance metrics. Next, Information about results and graph has been discussed in Section V. Finally, Conclusion is given in section VI.

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2. Related Work

They developed a NS-2 simulator for IEEE 802.15.4 standard and considered its different characteristics by performing various sets of simulations in beacon and non beacon enabled mode (J. Zheng *et al*, 2006). Quality of service analysis of three routing protocols AODV, DSR and DYMO for varying traffic loads in IEEE 802.15.4 mesh networks in non beacon enabled mode had been performed. (S. Mohanty *et al*, 2010). The results concluded that DSR and DYMO perform better than AODV in terms of packet delivery ratio, average end to end delay, total energy consumption and network lifetime. They worked on the performance evaluation of IEEE 802.15.4 MAC in the NS-2 network simulator in beacon enabled mode for a star topology and defined throughput energy delay tradeoff (G. Lu *et al*, 2004). They proposed a mathematical model for MAC protocol in beacon enabled mode and through simulation results analyzed it to be best tool for implementation of MAC parameters in a better networks (C.Burrati *et al*, 2010). NS2 simulator had been used to implement the performance of small scale peer to peer networks (Woon *et al*, 2006). Various performance metrics are analyzed such as throughput, packet delivery ratio, and average end to end delay. Various sets of experiments conducted to study different features of IEEE 802.15.4 wireless sensor networks. The effects of indirect and direct transmission, CSMA-CA mechanism, data payload size and beacon enabled mode are evaluated in terms of data throughput, delivery ratio and received signal strength indication (RSSI) and results shows the good performance in non-beacon mode (J.S Lee *et al*, 2006). They analyzed the IEEE 802.15.4 MAC standard for Wireless sensor network scenario with different routing protocol AODV, DYMO and XMESH under different duty cycle. Different duty cycle has been achieved by settling two parameters macbeacon order (BO) and mac superframe order (SO) so that power consumption remain low. Low duty cycle corresponds to lower power consumption while high duty represents higher power consumption. Results showed that XMESH routing protocol outperforms AODV and DYMO in terms of energy consumption in transmit mode, energy consumption in received mode, percentage of time in transmit mode, percentage of time in received mode and total charge consumption in WSNs (V. Kumar *et al*, 2011).

3. Overview of IEEE 802.15.4 WSNs

IEEE and Zigbee alliance have grouped together to develop a complete specification of 802.15.4. IEEE 802.15.4 protocol specification defines two layer, physical layer and MAC sublayer whereas zigbee defines the upper layer of the protocol stack. Physical layer specification embeds several features for reliable and flexible network such as energy detection (ED) within the current channel, link quality indication (LQI) for received packets, clear channel assessment (CCA) for CSMA-CA, activation and deactivation of the radio transceivers, channel frequency selection and data transmission & reception. Physical layer defines three frequency bands: 2.4 GHz with 16 channels & 250Kbps data rate, 915 MHz with 10 channels & 40 Kbps data rate and 868 MHz with 1 channels & 20 Kbps data rate. IEEE 802.15.4 utilizes the 2.4 GHz Industrial scientific & Medical (ISM) frequency bands. IEEE 802.15.4 MAC layer has several functions like generating networks beacons in beacon enabled mode, employing CSMA-CA mechanism for channel access, PAN association and disassociation, direct & indirect data transmission, allocation of a GTS by a PAN coordinator, synchronizing to the beacons. IEEE 802.15.4 Mac protocol specified two types of channel access mechanism: beacon enabled and non beacon enabled mode. These modes may be selected by a central node called PAN coordinator. In the Beacon enabled mode, channel access is done by slotted CSMA/CA Mechanism. In this mode, beacons are periodically sent by the PAN coordinator to synchronize all the devices. It also enables the allocation of Contention free time slots called guaranteed time slots (GTS) which determine the time slot during which nodes have to transmit the data. In Non- beacon enabled mode, channel access is governed by un-slotted CSMA/CA. PAN coordinator does not broadcast beacons. Moreover, it cannot have GTS & therefore contention free periods because the devices are not synchronized with each other. IEEE 802.15.4 standard defines the duty cycle by using two parameters, macBeaconOrder (BO) and macSuperframe Order (SO). IEEE 802.15.4 defines two types of devices that participate in a LR-WPAN network, reduced function devices (RFDs) and full function devices (FFDs). FFDs works in three different modes: a PAN coordinator, a coordinator, or a device. The PAN coordinator is the central controller of the network which starts the network and synchronizes all the devices in the network by periodically transmitting beacons frames. Each Personal area network must have exactly one PAN coordinator. It acts as a gateway to other networks. Coordinator acts as a router or an intermediate device and supports data routing between remote devices across multi-hop path. End devices do not have data routing functionality to relay messages to other end devices. They can only communicate with its parent node, the PAN coordinator or coordinators. Reduced function devices (RFD) work as an end devices and it cannot communicate with one another but can establish connection with FFDs & Full function devices (FFD) can work as a PAN coordinator or a coordinator or end devices. IEEE 802.15.4 operates in one of the two network topology, star & peer to peer topology shown in fig.1 (S. Mohanty *et al*, 2010). Peer to Peer topology allows mesh and cluster tree type of network. In star topology, one of the nodes chosen is FFD which is set as a PAN coordinator and all the other devices can be either FFDs or RFDs that communicates directly with the PAN coordinator. In peer to peer (mesh) topology, each device can communicate to every other device within its range. In

Cluster topology, all the FFDs and RFDs are connected to the network to form clusters as a leaf nodes. IEEE 802.15.4 defines a superframe structure shown in fig. 2

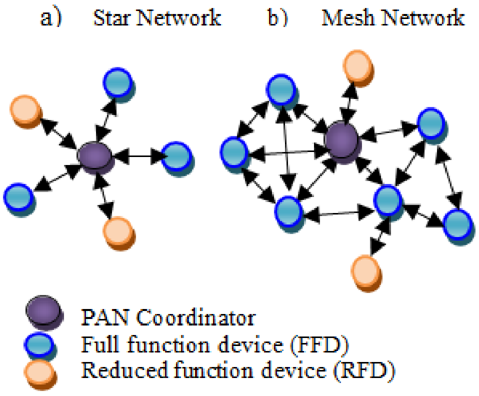

Fig.1 Topology supported by IEEE 802.15.4

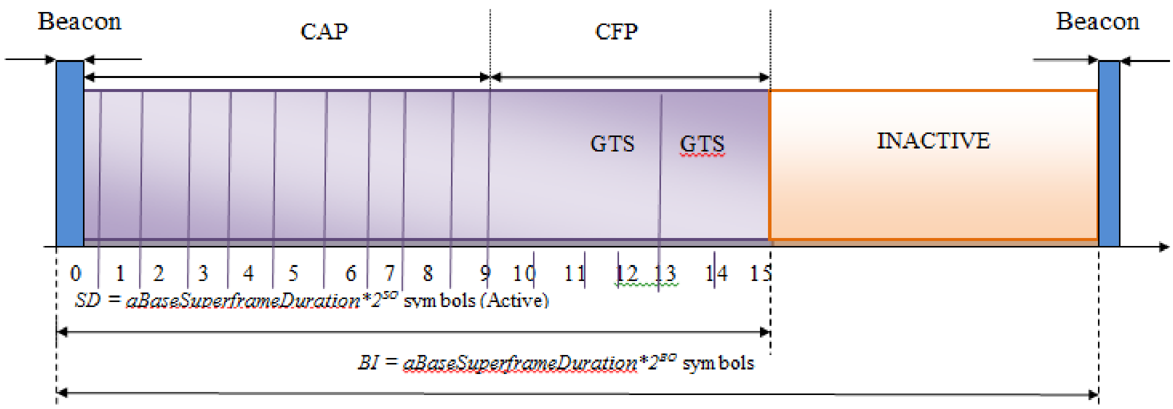

Fig.2 Superframe Structure of IEEE 802.15.4

(J.S Lee *et al*, 2006). It is divided into two parts – Active part and Inactive part. Active part composes of Beacon frame, Contention access period (CAP) & Contention free period (CFP).

According to IEEE802.15.4 standard (Jennifer Yick *et al*, 2008), the superframe structure active period is called superframe duration (SD) which is divided into 16 equally sized time slots and beacon interval (BI) defines the time between two consecutive beacon frames.

$BI = aBaseSuperframeDuration \times 2^{BO}, 0 \le BO \le 14.$

$SD = aBaseSuperframeDuration \times 2^{SO}, 0 \le SO \le 14.$

For 250 Kbps, 2.4 GHz frequency band, abasesuperframe duration = 15.36 ms to 251.3 s corresponding to SO = 0 to 14.

Where abasesuperframe duration = 960 symbols when SO = 0. In a PAN, the value of SO must be less than or equal to the BO. For non beacon enabled mode BO=SO=15. In this case, a coordinator shall not transmit beacons and GTS shall not be permitted. BO=SO means there is no inactive part of the superframe or full duty cycle.

In a beacon enabled mode, superframe structure is used for communication between devices and beacon is transmitted in the first slot of each superframe whereas in non beacon enabled mode, turn off the beacons transmissions. In beacon mode after beacon, CAP starts immediately & all the devices can access the channel using slotted CSMA/CA mechanism in this period (C.Burrati *et al*, 2010). After CAP, CFP provides GTS, specific time slot to a particular device. Therefore, a device with an allocated GTS will start transmitting during that GTS without using the CSMA/CA mechanism.

4. Simulation Set Up

The Simulation was carried out using Qualnet 6.1 Network Simulator. The main objective of simulation study is to compare the performance of beacon and non beacon enabled IEEE 802.15.4 multi-hop star topology with different data rates for routing protocol DYMO (I. Chakeres *et al*, 2007). In this scenario, the simulations are carried out on a network of 50 nodes placed randomly in the area of 50m*50m. In the simulations model, a star topology as shown in figure 3 is formed with one PAN coordinator, 25 Full function device (FFDs), 24 reduced function device (RFDs) and 5 CBR applications. PAN Coordinator is placed at the centre of the simulation area and it is the main powered device and does not require battery like FFD and RFD. In many of the WSN applications, all the devices deliver data to a single sink server. Similarly here in the simulations model all the end devices communicate to the main controller (PAN coordinator). The Simulation parameters for this model are shown in table 1. Here, micaz energy model have been used which gives the information about the energy consumed by the devices in different modes. Different data rates of 0.1s, 0.2s, 1s, 2s, 5s have been applied in

order to analyze the impact of different values of BO and SO on a star network. Fig.3 shows the qualnet visualization scenario of a 50 node star network.
This paper focuses on a performance analysis of beacon & non-beacon enabled mode of IEEE 802.15.4 with star multi-hop topology.

In all experiments, different values of Beacon order (BO) and superframe order (SO) are used. The PAN coordinator periodically sends the beacon frames according to the BO and SO parameters.

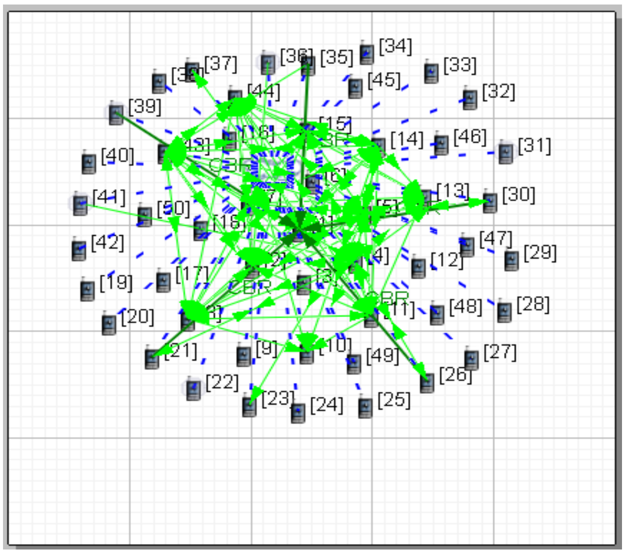

Fig.3 Qualnet visualization scenario for a 50 node STAR Network

Table1 Simulations Parameters

Parameter Name	Parameter Value
No. of Nodes and Area	50 and 50m*50m
No. of items and Payload Size	1000 and 50 bytes
Channel Frequency and data rate	2.4 GHz and 250 Kbps
Path Loss Model	Two Ray Model
Transmission range	40 m
Transmission Power	0dBm
Physical and MAC Layer	IEEE 802.15.4
Energy Model	MICAZ Mote
Battery Model	Simple Linear,1200 mAhr
Modulation	O_QPSK
Simulation Time	150 second
Beacon order and Superframe order	3, 4, 5, 6, 15
Data rate	0.1, 0.2, 1, 2, 5 sec
Traffic type	CBR
Routing Protocol	DYMO

Throughout the analysis, SO=BO (100% duty cycle have been considered. It means when superframe order changes, beacon order also changes. Acknowledgement RTS/CTS have not been used since they create delay and overhead. In this study, effect of BO and SO has been analyzed under different data rates for on demand reactive routing protocol DYMO on IEEE 802.15.4 star topology. Various performance metrics used are throughput, average jitter, average end to end delay, total energy consumption, residual battery consumption and percentage of time in sleep mode.

5. Simulation Results

The impact of BO and SO is one of the most important roles of the PAN coordinator. This section presents the simulation results of following metrics for evaluation of the performance of the routing protocol DYMO.

5.1 Throughput

Throughput is defined as the average rate of successful data packets delivery across a network. It is generally measured in bits/sec.

Figure 4 shows the variation of throughput against different data rates. Higher data rates mean lesser no. of packets per second is sent into the network. Here, for lesser data rate, higher throughput is observed and as data rate is increased, throughput gets low. The reason behind it is that at low data rate, large no. of packets are sent means more bits per second are transmitted thus resulting in higher throughput. For all values of BO=SO, throughput is maximum at low data rate. It can be realized that throughput of DYMO is maximum in non beacon enabled mode when BO=SO=15 as compared to beacon enabled mode. Low BO and SO values produce lower network throughput due to the frequent overhead of the beacons frames.

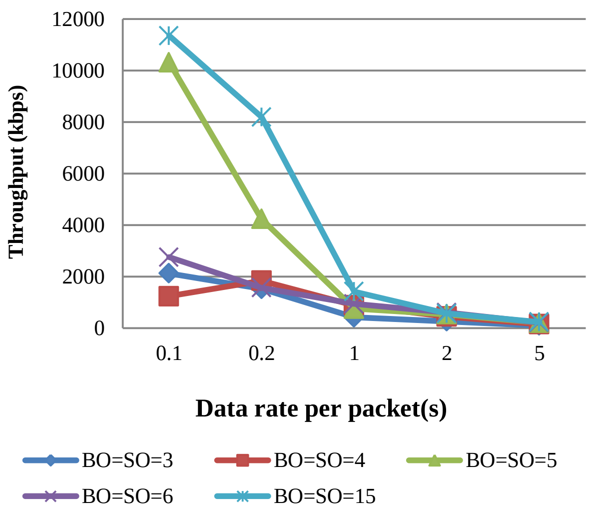

Fig. 4 Throughput versus different values of BO=SO

5.2 Average Jitter

Average Jitter measures the variation time in the arrival of packets even if they are sent at the same time. These delays may be due to the network congestion, route discovery, queuing, propagation and transmit time. Jitter should be low for better performance of the network.

In Figure 5, Average jitter is shown against varying data rates. With increase in data rates the average jitter of

DYMO also increase. At low data rates jitter is low. Non-beacon mode has lesser jitter as compared to beacon enabled mode for all type of traffic loads.

5.3 Total energy consumption

It is defined as the amount of energy consumed by each micaz sensor nodes during transmits, receive, idle and sleep time. The unit of energy consumption used in simulation is mjoule.

Figure 6 presents the total energy consumption of a routing protocols for varying beacon order and superframe order under different data rates. At low values of data rates, total energy consumption is low. As data rate per packet is increased to 5 total energy consumption also increased. DYMO have lower energy consumption in non beacon enabled mode as compared to beacon enabled mode. As BO and SO values increased, total energy consumed is decreasing for higher data rates.

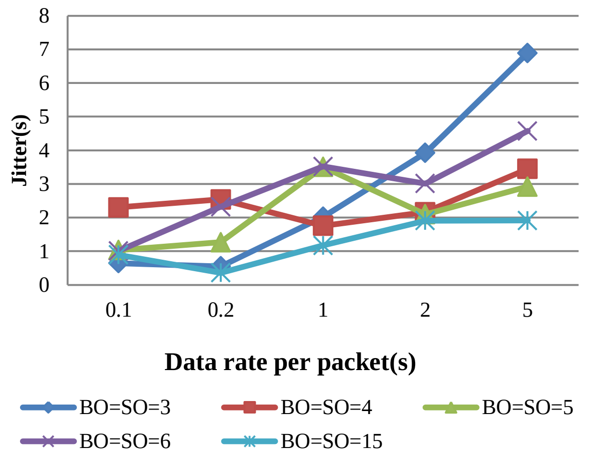

Fig.5 Average jitter versus different values of BO=SO

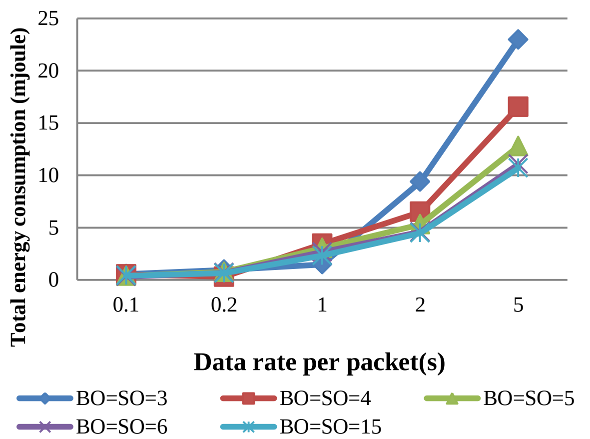

Fig.6 Total energy consumption versus different values of BO=SO

5.4 Average end to end delay

Average End to end delay refers to the time taken for a packet to travel from source to destination. It is the average delay suffered by all the packets in the network.

Figure 7 shows the performance of average end to end delay for different values of SO and BO against varying traffic loads. The overall end to end delay performance DYMO is better at high data rates. The average end to end delay is low at BO=SO=15 for all traffic loads. Therefore, non beacon enabled mode performs better than beacon enabled mode. In beacon enabled mode, beacons are generated frequently which may cause buffered packets, collision and retransmission thus resulting in higher delay as compared to beaconless mode. For large values of BO and SO with same data rates, higher delay is observed in beacon enabled mode. This is because larger BO and SO means longer inactive period so producing higher delay. For all values of BO=SO, the effect of increasing data rate results in a significantly low delay.

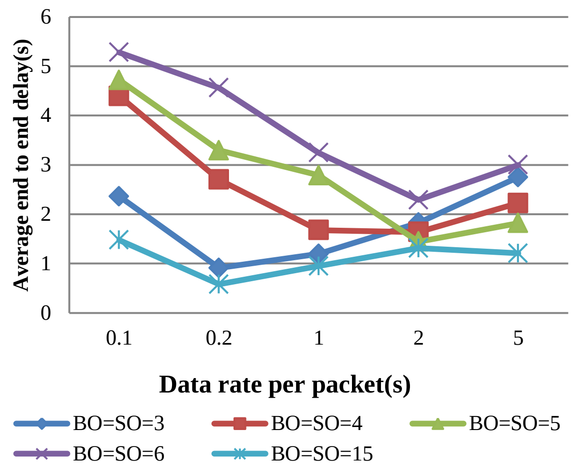

Fig.7 Average End to End delay versus different values of BO=SO

5.5 Percentage of time in sleep mode

It is indirectly proportional to the duty cycle. It means the percentage of time each node is in sleep mode. For low duty cycle, percentage of time each node in sleep mode will be more.

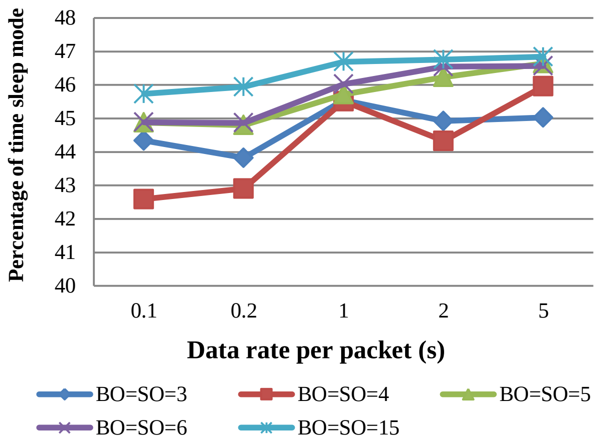

Fig.8 Percentage of time in sleep mode versus different values of BO=SO

Figure 8 shows the performance of percentage of time in sleep mode with varying BO and SO for different traffic loads. Performance of non beacon mode is better than beacon mode as it has low duty cycle due to large percentage of time in sleep mode. For increased in BO and SO from 3 to 15, duty cycle is decreased. It clearly shows that DYMO has low duty cycle at high data rates.

5.6 Residual Battery consumption

In figure 9, at low data rate, battery consumed is almost same for all values of BO and SO. Battery consumption is decreased at high data rate. With increase in values of BO=SO at high data rates, battery consumption is also increasing. Therefore, it can be realized that DYMO consumed more battery in non beacon enabled mode as compared to beacon mode.

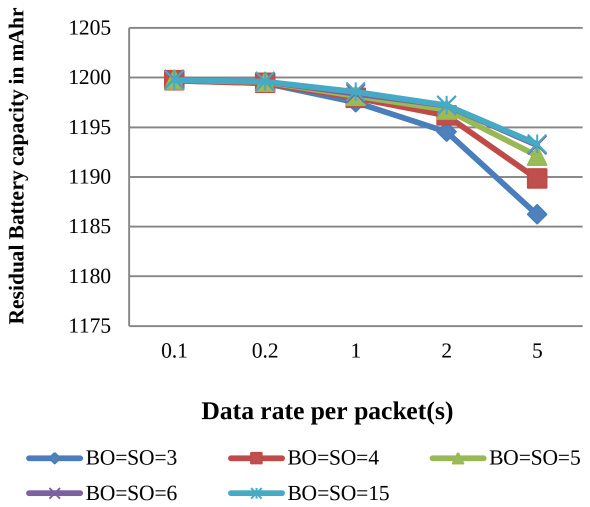

Fig.9 Residual Battery consumption versus different values of BO=SO

Conclusions

A simulation based on impact of MAC parameters (beacon and superframe order) on IEEE 802.15.4 multi-hop star network is investigated in this paper. Various performance metrics have been analyzed with different traffic loads for on demand reactive routing protocols DYMO in Qualnet simulator 6.1. From the simulation analysis, it can be concluded that performance of DYMO is better in non beacon enabled mode. For low values of data rates, network performance parameters are better for all BO and SO. Further, effect of BO and SO can be considered for different network topologies, mesh and clusters and various metrics can be analyzed for beacon and non beacon enabled mode.

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