Performance Analysis of Quality of Service Parameters for IEEE 802.15.4 Star Topology using MANET routing

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ABSTRACT

IEEE 802.15.4 is the emerging next generation standard specifically designed for low-rate wireless personal area networks (LR-WPAN), which suit wireless sensor networks applications. It attempts to provide a low cost, low power and short range wireless networking standards. This paper provides the performance analysis of Quality of Service parameters of WSN based on IEEE 802.15.4 star topology using MANET routing. The data packet delivery ratio, average end-to-end delay, total energy consumption, network lifetime and percentage of time in sleep mode are investigated as the performance metrics. The results show that DSR performs better than DYMO, AODV routing protocols for varying traffic loads in star topology beacon enabled mode.

.Categories and Subject Descriptors

C.2 [**Computer-Communications Networks**]: Network Architecture and Design—Network communication, Network topology, Network protocols-Routing protocols.

General Terms

Measurement, Performance

Keywords

IEEE 802.15.4, ZigBee, QualNet, WSN, MANET.

1. INTRODUCTION

Wireless Sensor Networks (WSNs) have achieved worldwide attention in recent years due to growth in Micro-Electro-Mechanical Systems (MEMS) technology. It has eased the development of smart sensors [7, 8] depending upon different applications. They have been applied to plethora of applications that connect the physical world to the virtual world due to their vast potential, energy efficient design and easy deployment. It is an "In situ" sensing technology where tiny, autonomous and compact devices called sensor nodes or motes are deployed in a remote area to detect phenomena, collect and process data and transmit sensed information to users. Sensor nodes or motes in WSNs are small sized and are capable of sensing, gathering and processing data while communicating with other connected nodes in the network, via the radio frequency (RF) channel. The growth of mobile computing devices including laptops, personal digital assistants (PDAs), and wearable computers have created a demand for wireless personal area networks (WPANs). To meet these challenges, IEEE 802.15.4 [4] low rate wireless personal area network (LR-WPAN) standard has been introduced. It is basically implemented for three reasons: the need for low-cost, low-power and short-range communication. Thus it suits wireless sensor network applications where a large number of tiny smart sensors having the low power, low range and low bandwidth are deployed in an ad hoc manner for the purpose of automation, tracking and surveillance in a terrain. The main objective of this standard is to support short range applications like in automotive monitoring and control in industry automation, home automation, ubiquitous and pervasive health care in medical sectors and sensor-rich environments [1]. Such applications require a small, low-cost, highly reliable technology that offers long battery life, in months or even years. ZigBee [15] is an example, which is an open specification, built on the IEEE 802.15.4 Physical and MAC layer standard.

The organization of the paper is as follows. Section 2 discusses related works for performance evaluation of IEEE 802.15.4 topology in various simulation environments. The overview of IEEE 802.15.4 protocol is discussed briefly in Section 3. Next, simulation set up has been discussed in Section 4. In Section 5, simulation results have been discussed. Finally, we conclude our work in Section 6.

2. RELATED WORK

J. Zheng and M.J. Lee [11] implemented the IEEE 802.15.4 standard on NS2 simulator and provided the comprehensive performance evaluation on 802.15.4. The literature comprehensively defines the 802.15.4 protocol as well as simulations on various aspects of the standard. It mainly confined to performance of IEEE 802.15.4 MAC. Similarly in [5] the authors provided performance evaluations of IEEE 802.15.4 MAC in becon-enabled mode for a star topology. The performance evaluation study revealed some of the key throughput-energy-delay tradeoff inherent in IEEE 802.15.4 MAC. J.S.Lee [10] attempted to make a preliminary performance study via several sets of practical experiments, including the effects of the direct and indirect data transmissions, CSMA-CA

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mechanism, data payload size, and beacon-enabled mode. T.H.Woon and T.C.Wan [13] extended existing efforts but focuses on evaluating the performance of peer-to-peer networks on a small scale basis using NS2 simulator. The author analyzed the performance metrics such as throughput, packet delivery ratio, and average delay. In addition, they proposed ad hoc sensor networks (AD-WSNs) paradigm as part of the extension to the IEEE 802.15.4 standard. In [9] the authors presented a novel mechanism intended to provide Quality of Service (QoS) for IEEE 802.15.4 based Wireless Body Sensor Networks (WBSN) used for pervasive healthcare applications. The mechanism was implemented and validated on the AquisGrain WBSN platform.

3. IEEE 802.15.4 Overview

The IEEE 802.15.4 defines the physical layer (PHY) and medium access control sublayer (MAC) specifications to support energy constraint simple devices to work in wireless personal area networks(WPANs).To provide the global availability, the IEEE 802.15.4 devices use the 2.4 GHz industrial scientific and medical (ISM) unlicensed band. The standard offers two PHY options based on the frequency band. Both are based on direct sequence spread spectrum (DSSS). The data rate is 250 kbps at 2.4 GHz with offset quadrature phase shift keying (OQPSK), 40 kbps at 915 MHz and 20 kbps at 868 MHz with binary phase shift keying (BPSK). There is a single channel between 868 and 868.6 MHz, 10 channels between 902.0 and 928.0 MHz, and 16 channels between 2.4 and 2.4835 GHz. Receiver sensitivities are −85 dBm for 2.4 GHz and −92 dBm for 868/915 MHz. These accommodate over air data rates of 250 kbps in the 2.4 GHz band, 40 kbps in the 915 MHz band, and 20 kbps in the 868 MHz. A total of 27 channels are allocated in 802.15.4, including 16 channels in the 2.4 GHz band, 10 channels in the 915 MHz band and 1 channel in the 868 MHz band. Physical layer provides means for bit stream transmission over the physical medium. The key responsibilities of PHY are activation and deactivation of the radio transceiver, frequency channel tuning, carrier sensing, received signal strength estimation (RSSI & LQI) , data coding and modulation and Error correction etc.

IEEE 802.15.4 supports two different device types that can communicate in an LR-WPAN network: a full-function device (FFD) and a reduced-function device (RFD). The FFD can operate in three modes to serve as a PAN coordinator, a coordinator, or a device. An FFD can communicate to RFDs or other FFDs, while an RFD can communicate only to an FFD. RFD does not have the capability to relay data messages to other end devices. It is mainly used for applications that are extremely low resource in capability like a light switch or a passive infrared sensor. They would be only associate with a single FFD at a time to transfer data. Depending on the application requirements, an IEEE 802.15.4 LR-WPAN may operate in either of two topologies: the star topology or the peer-to-peer topology. In star topology, devices are interconnected in form of a star in which there is a central node PAN coordinator and all the network nodes (FFDs and RFDs) can directly communicate only to the PAN. In the star topology the communication is established between devices and a single central controller, called the PAN coordinator. The PAN coordinator is the primary controller of the PAN. All devices operating on a network have unique 64-bit addresses. This address may be used for direct communication within the PAN, or a short address may be allocated by the PAN coordinator when the device associates and used instead. The PAN coordinator might be mains powered, while the devices will most likely be battery powered. Applications that benefit from a star topology include home automation, industry automation, personal computer (PC) peripherals, toys and games, and personal health care systems.

An IEEE 802.15.4 network can work in either beacon-enabled mode or non-beacon-enabled mode. In beacon-enabled mode, PAN coordinator broadcasts beacons periodically to synchronize the attached devices. In non-beacon-enabled mode, PAN coordinator does not broadcast beacons periodically, but may unicast a beacon to a device that is seeking beacons. In addition to CSMA/CA-based transmissions, the beacon-enabled mode provides a contention-free guaranteed-time-slots (GTS) mechanism to support time-critical data deliveries. The power-saving mechanism is provided through the beacon-based superframe structure. In this paper, we focus on the IEEE 802.15.4 beacon-enabled mode star topology. A superframe presented in Figure 1 begins with a beacon issued by a PAN Co-ordinator, and consists of an active portion and an inactive portion. The active portion with 16 time slots is composed of three parts: a beacon, a contention access period (CAP), and a contention free period (CFP). The beacon is transmitted by the coordinator at the start of slot 0, and the CAP follows immediately after the beacon. In the CAP, a slotted CSMA/CA approach is used for devices to access the channel and to transmit non-time-critical messages and MAC commands. For 250kbps, 2.4GHz frequency the duration (also called beacon interval or BI) of a superframe ranges from 15ms to 251.3s corresponding to SO=0-14. The coordinator and devices can communicate with each other during the active period and enter the low-power phase during the in-active period. This feature is particularly interesting for WSN applications, where energy consumption and network lifetime are main concerns. BI and SD are determined by two parameters, the Beacon Order (BO) and the Superframe Order (SO), respectively.

$$BI = aBaseSuperframeDuration \times 2^{BO}$$

$$SD = aBaseSuperframeDuration \times 2^{SO}$$

where $0 \leq SO \leq BO \leq 14$

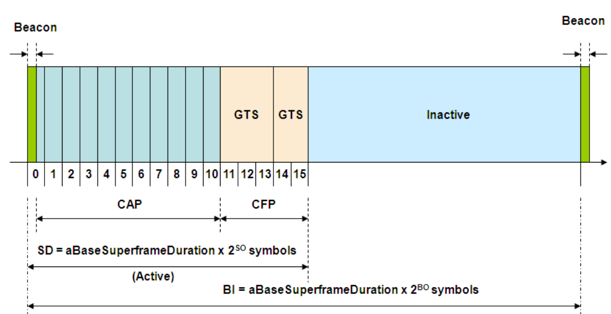


Figure 1. IEEE 802.15.4 Superframe Structure

4. SIMULATION SETUP

The main objective of this simulation study was to evaluate the performance of different popular reactive wireless mobile ad hoc routing protocols like AODV [2], DSR [3] and DYMO [6] on static IEEE 802.15.4 star topology for varying traffic loads. The simulations have been performed using QualNet version 4.5 [14], a software that provides scalable simulations of wireless networks. In the simulation model, a star topology with one PAN Co-ordinator and 100 devices are uniformly deployed in an area of 50mx50m. PAN is static mains powered device placed at the centre of the simulation area. Only the uplink traffic i.e. devices to PAN Co-ordinator are considered in the simulations which suits WSN application like automation industry where a large number of devices communicates to a single sink server for data delivery and processing. The devices have transmission range of one hop away from PAN Coordinator in star topology. The simulation parameters are listed in Table 1. The fact that BO=SO assures that no inactive part of the superframe is present. A low value of this parameter implies a great probability of collisions of beacons of beacon frames as these would be transmitted very frequently by coordinators. On the contrary, a high value of the BO introduces a significant delay in the time required to perform the MAC association procedure since channel duration which is a part of association procedure is proportional to BO. In our simulation model, function for acknowledging the receipt of packets is disabled. It is due to the fact that RTS/CTS overhead mechanism is too expensive for low data rate WSN application for which 802.15.4 is designed. The CBR traffic with the following average packet rates: 0.1 packet per second (pps), 0.2 pps, 1 pps, 5 pps and 10 pps are used. Multiple-to-one CBR application traffic, which consists of 20 application sessions from farthest side nodes like 1, 2, 4, 6, 8, 10, 20, 21, 40, 60, 61, 80, 81, 91, 92, 94, 96, 98, 99 and 100 to PAN Co-ordinator node 55. The simulation results have been averaged over 10 different seeds values from 1 to 10.

TABLE 1. SIMULATION PARAMETERS

Parameter	value
No. of Nodes and Area	100 and 50m*50m
Simulation time	170M,85M,18M,5M and 3Minute
Channel frequency and data rate	2.4GHz and 250kbps
Transmission range	35meter
TX-Power	0dBm
Path Loss Model	Two Ray Model
Phy and MAC Model	IEEE 802.15.4
Energy Model	MICAZ Mote
Battery Model	Simple Linear,1200 mAhr,
No. of items and Payload Size	1000 and 50 bytes
BO and SO	5

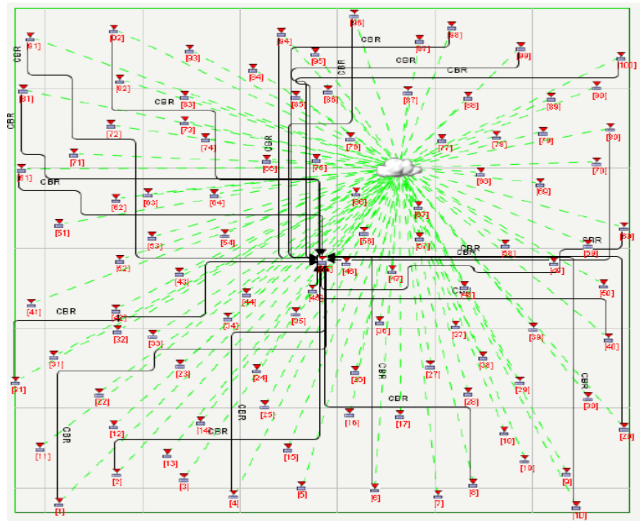


Figure 2. Simulation Setup for STAR Topology

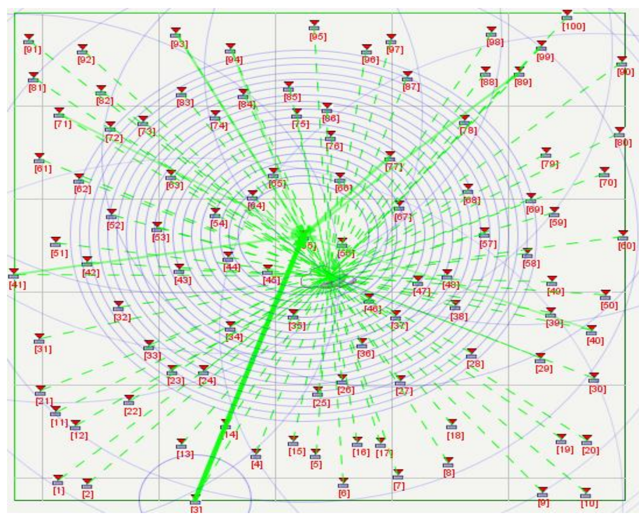


Figure 3. QualNet animator during simulation execution

To evaluate QoS parameters performance for IEEE 802.15.4 star topology using different reactive MANET routing, we have used the following QoS performance metrics.

Packet delivery ratio: It is the ratio of the number of data packets successfully delivered to destination nodes to the total number of data packets sent by source nodes.

Average End-to-End delay: It indicates the length of time taken for a packet to travel from the CBR (Constant Bit Rate) source to the destination. It represents the average data delay an application experiences during transmission of data.

Energy Consumption (mJoule): This is amount of energy consumed by MICAZ Mote devices during the periods of transmitting, receiving, idle and sleep. The unit of energy consumption used in the simulations is mJoule.

Network Lifetime: This is defined as the minimum time at which maximum number of sensor nodes will be dead or shut down during a long run of simulations.

Percentage of time in Sleep mode: It indicates the percentage of time in sleep mode. It indirectly relates to duty cycle .The more is the percentage of time in sleep mode, the less is the duty cycle .It is mainly useful in WSN applications which demand low duty cycle.

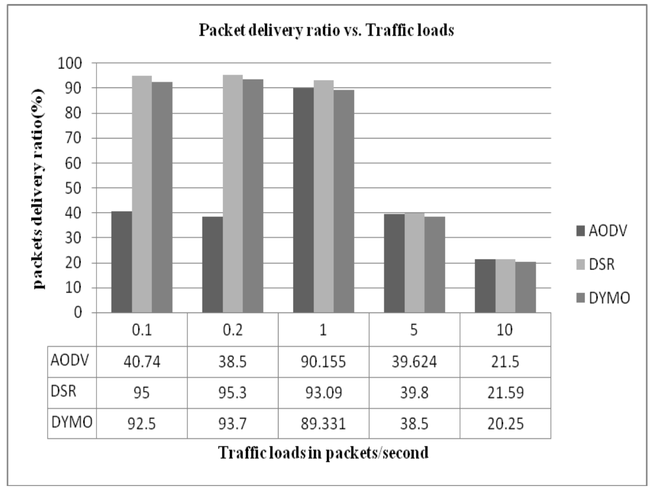
5. SIMULATION RESULTS DISCUSSION

This section presents the simulation results of various performance metrics for evaluation of on demand reactive routing protocols like ADOV, DSR and DYMO on IEEE 802.15.4 star topology using varying traffic loads.

The Figure 4 shows the performance of Packet delivery ratio for different varying traffic loads. In all types of traffic load, DSR performs better than AODV and DYMO. The PDR of AODV increases from 40.74% to 90.15% when the traffic load changes from 0.1 packet per second to 1 packet per second and then decreases .On the other hand, DSR shows nearly 95% packet delivery ratio at low traffic loads except at high traffic loads i.e. at 5pps and 10pps where its value decreases to 21.5%. DYMO shows better performance of PDR at low traffic rather than at high traffic loads in comparison to AODV. DSR is performed well due to its source routing based aggressive caching approach which is very effective as the cached routes never expire.

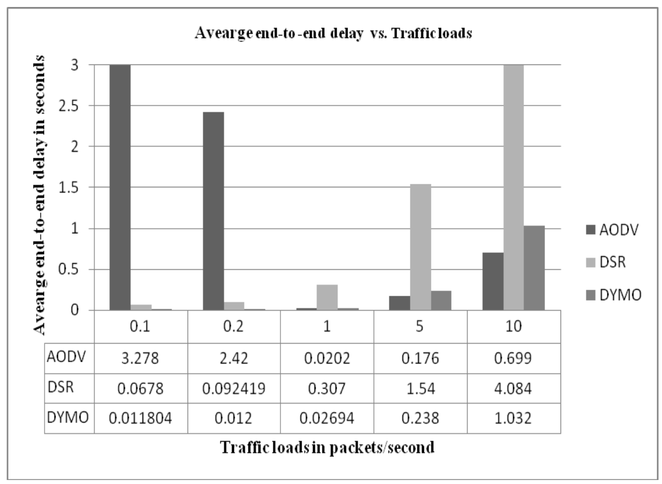
The Figure 5 shows the performance of average end-to- end delay for different traffic loads. The average end- to- end delay of a packet depends on delays at each hop comprising of queuing, channel access and transmission delays, the number of hops, route discovery latency. The overall average end-to-end delay performance of the DYMO and DSR is better than AODV .The average end to end delay is the best at 1 packet per second for all three routing protocols. DSR has a significantly low delay due to its source routing, which helps to know the complete path to the destination node for data transferring rather than AODV approach to the route discovery process.

Figure 6 shows the performance of total energy consumption of three routing protocols for varying traffic loads. The total energy consumption is the energy consumption in transmission, reception, idle and sleep. It is noticed while calculating total energy consumption in statistics that the maximum energy dissipation occurred during idle mode while reception consumes greater energy than transmission for transferring data packets. During sleep time, there is no energy consumption. The total energy consumption of three routing protocols decreases exponentially when it transferred packets from low traffic loads to high traffic loads. The DSR routing protocols performs better than AODV and DYMO at all specified traffic loads due to its low control overhead. It is due to the fact that a routing protocol



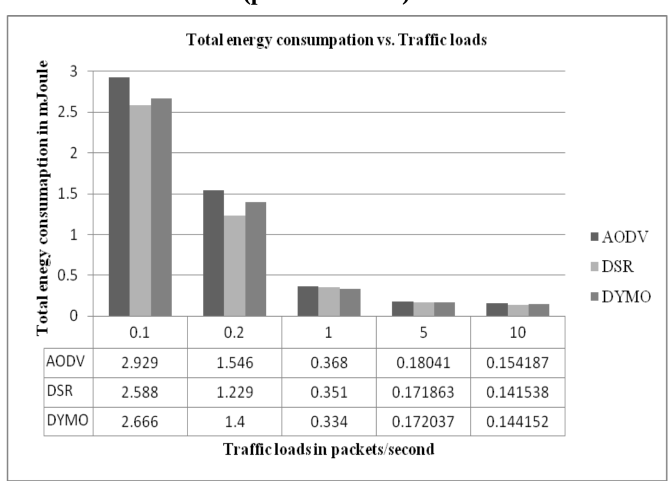
	0.1	0.2	1	5	10
AODV	40.74	38.5	90.155	39.624	21.5
DSR	95	95.3	93.09	39.8	21.59
DYMO	92.5	93.7	89.331	38.5	20.25

Figure 4. Packet delivery ratio verses Traffic loads (packets/second)



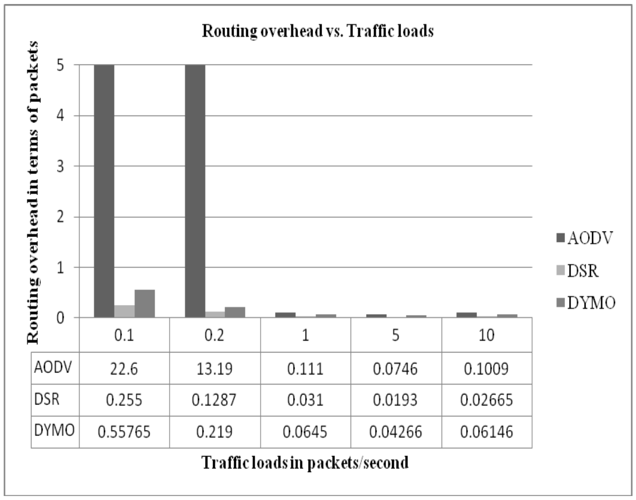
	0.1	0.2	1	5	10
AODV	3.278	2.42	0.0202	0.176	0.699
DSR	0.0678	0.092419	0.307	1.54	4.084
DYMO	0.011804	0.012	0.02694	0.238	1.032

Figure 5. Average end– to-end delay verses Traffic loads (packets/second)



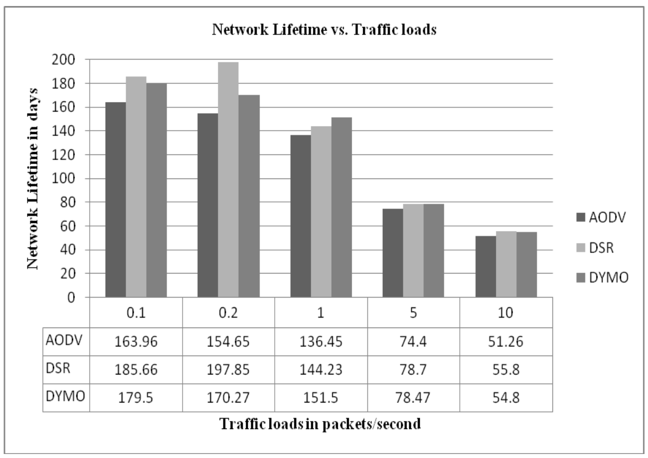
	0.1	0.2	1	5	10
AODV	2.929	1.546	0.368	0.18041	0.154187
DSR	2.588	1.229	0.351	0.171863	0.141538
DYMO	2.666	1.4	0.334	0.172037	0.144152

Figure 6. Total energy consumption verses Traffic loads (packets/second)



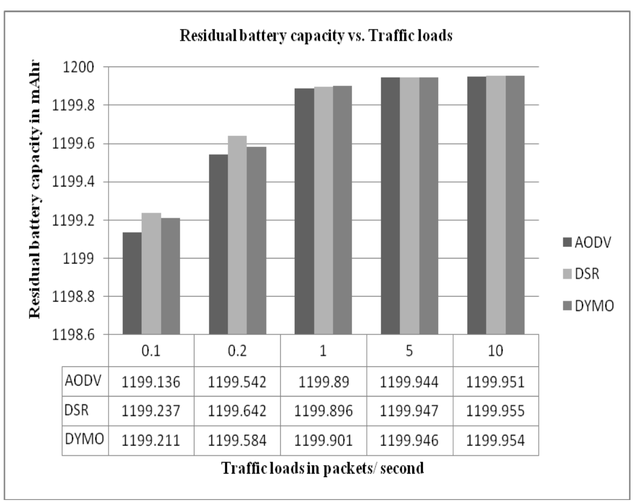
	0.1	0.2	1	5	10
AODV	22.6	13.19	0.111	0.0746	0.1009
DSR	0.255	0.1287	0.031	0.0193	0.02665
DYMO	0.55765	0.219	0.0645	0.04266	0.06146

Figure 7. Routing overhead verses Traffic loads (packets/second)



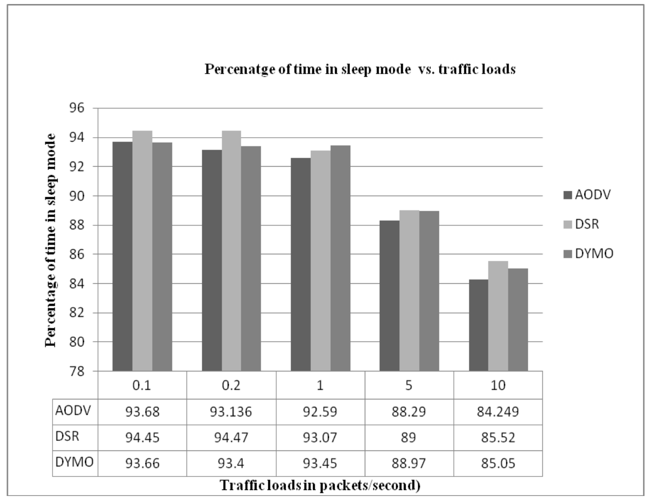
	0.1	0.2	1	5	10
AODV	163.96	154.65	136.45	74.4	51.26
DSR	185.66	197.85	144.23	78.7	55.8
DYMO	179.5	170.27	151.5	78.47	54.8

Figure 8. Network Lifetime verses Traffic loads (packets/second)



	0.1	0.2	1	5	10
AODV	1199.136	1199.542	1199.89	1199.944	1199.951
DSR	1199.237	1199.642	1199.896	1199.947	1199.955
DYMO	1199.211	1199.584	1199.901	1199.946	1199.954

Figure 9. Residual battery capcity verses Traffic loads (packets/second)



	0.1	0.2	1	5	10
AODV	93.68	93.136	92.59	88.29	84.249
DSR	94.45	94.47	93.07	89	85.52
DYMO	93.66	93.4	93.45	88.97	85.05

Figure 10. Percentage of time in sleep mode verses Traffic loads (packets/second)

with more control overhead would consume more energy than the routing protocol with less control overhead which can be shown in Figure 7.

The Figure 8 shows the performance of network lifetime for different varying traffic loads. The network lifetime calculation in our simulation based on residual battery capacity as shown in Figure 9 after running it full battery capacity 1200mAHr to the respective simulation time over varying traffic loads. The DSR routing protocol has maximum lifetime in comparison to ADOV and DYMO. It is again due to fact of low control overhead of DSR. DSR minimizes the overall network bandwidth overhead because of the fact that it does not use periodic routing messages. By doing so DSR also tries to conserve battery power as well as avoidance of routing updates that are large enough. The network bandwidth is reduced because there are not periodic message advertisements. By not sending or receiving advertisements the battery power is also reserved by DSR.

The Figure 10 presents the performance of percentage of time in sleep mode for varying traffic loads. From the figure, it can be noticed that less than 1 mAhr is required to send data at different traffic loads. The IEEE 802.15.4 supports a Battery Life Extension (BLE) mode, in which the back-off exponent is limited to the range 0-2. This greatly reduces the receiver duty cycle in low traffic rate applications. However, in dense networks, this mode results into excessive collision rates. It is due to energy efficient IEEE 802.15.4 MAC which minimizes low duty cycle on RFD so send data packets. It clearly shows that DSR performs better than other two routing protocols. In directly indicates that DSR has the least duty cycle than other two routing protocols.

6. CONCLUSIONS

A simulation based performance analysis of quality of service parameters for WSN based on IEEE 802.15.4 star topology beacon enabled mode is investigated in this paper. Quality of service metrics have been compared with on demand routing protocols like AODV, DSR and DYMO for varying traffic loads in QualNet 4.5 software. From the simulation results of our studies and analysis, it can be concluded that on an average DSR performs better than DYMO and AODV at low traffic loads, which suit WSN applications; but at high traffic loads all three routing protocols nearly behave same. However, the overall performance of the three protocols on IEEE 802.15.4, which is standard for WSNs is not quite good. The major reason behind the performance degradation is due to all these protocols which are specifically designed for mobile ad-hoc network to combat frequently topology changes. To meet these challenges of performance degradations, new routing protocols should be designed for IEEE 802.15.4 networks keeping in view of these routing protocols key features, which are still performing well in static Wireless Sensor Networks.

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