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Congestion free opportunistic multipath routing load balancing scheme for Internet of Things (IoT)

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ABSTRACT

Internet of Things (IoT) interconnects billions of devices to form a heterogeneous network over the Internet. The heterogeneous communication infrastructure of IoT opens a door for the research community to design new protocols by utilizing minimal resources of these tiny devices to achieve accurate results. Therefore, the research community suggests various techniques to resolve the load balancing issue of IoT and prolong the network lifetime. Although, these techniques are effective at some stage in managing the load balancing issue, they have some side effects on network performance such as high communication costs, end-to-end (E2E) delay, packet lost ratio (PLR), throughput, and individual sensor devices lifespan, etc. Therefore, an efficient lightweight load balancing routing protocol is needed to be developed to address the aforementioned issues in IoT networks. In this paper, Dynamic hop selection static routing protocol (DHSSRP) is proposed to resolve the load balancing issue of IoT networks in congestion-free and priority-based communication infrastructure. The proposed DHSSRP routing protocol priorities the sensitive/critical information of sensors devices with static routing and divert the neighbor's sensor communication with an alternate hop selection path, which manages the network traffic in a congestion-free environment. The traffic management of the DHSSRP routing protocol based on priority-based information balances the energy consumption with a balanced traffic environment, which maximizes the lifespan of the deployed IoT devices in the network. The results captured during simulation for the proposed scheme were compared with the field-proven scheme, which showed a significant improvement for the metrics, such as communication cost, computational cost, traffic congestion, throughput, PLR, and network lifetime. Moreover, the results observed for an individuals sensor devices to participate in the network until the end-stage showed a 95.8 % result with the same onboard battery power.

1. Introduction

The demand for the Internet of Things (IoT) increases with the passage of the time, due to its induction in every aspect of life [1]. Wireless sensor networks (WSNs) open the door of IoT technologies in the real world from its previous experience by sensing, collecting, and processing information at a remote location [2]. WSNs contains hundreds or thousands of wireless nodes, which collect information according to their assigned task and share it with a remote destination. Similarly, IoT is the revolutionary technology, which interconnects billions of sensor devices to form a heterogeneous network over the Internet.

Wireless sensor devices, which are called the building blocks of IoT has the capabilities to collect, store, process, and communicate the information in the network. The interconnection of these devices in a heterogeneous environment brings a lot of challenges for the research community, such as network architecture, efficient data collection, security, storage, and reliable traffic management. Moreover, wireless sensors are susceptible to various threats, due to their limited resources such as onboard power, memory, communication, and processing. Therefore, an efficient communication infrastructure of sensor devices can maximize its performance in terms of accurate results with minimal resource utilization [3,4].

In the real world, where IoT networks are deployed have some associated issues, such as radio resource management of sensor devices. Therefore, this problem became very challenging for the research community, because the number of smart devices is very large to interconnect and established a communication infrastructure. Similarly, the overall performance of any wireless network greatly depends on the dimensional resources of participating devices such as frequency, time slot, channel fluctuation, and network traffic. Moreover, the induction of IoT devices in new applications increases the importance of these devices for improved spectral efficiency in terms of PLR, throughput, and latency [5,6].

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In the heterogeneous environment of IoT networks, the battery lifetime of sensor devices is the main concern to be considered, because these devices use hop count information to transmit their collected data from source to destination location. Likewise, as the number of sensor devices increases, the traffic congestion in the network is also increasing, which uses the battery power of deployed sensor nodes to process this information in the network. Therefore, the heterogeneous communication infrastructure and high traffic rate increases the power consumption of the sensor devices onboard battery power, which at the end minimizes the overall lifespan of the deployed network [7].

Moreover, the severity of battery power utilization increases, when the source device is at some distance from the edge node/base station (BS). The energy consumption of sensor devices in the transmission increases with a faster rate with high distance parameters, which decreases the network lifetime [8]. Routing protocols in wireless technology play a vital role to address load balancing, security, and efficient traffic management related issues. Therefore, routing protocol in wireless technology such as WSNs, Ad hoc networks, and IoT is still a hotspot area for researchers to devise new techniques and resolve this issue. Sensor devices have limited battery power, therefore, they need efficient utilization to extend their lifecycle in an operational network.

The literature of IoT in terms of load balancing schemes contain various cluster-based protocols that have been used in the recent past to address the load balancing issue [9]. Most of the researchers used the Low-energy adaptive clustering hierarchy (LEACH) protocol in their proposed models to address the aforestated issue of load balancing in IoT. Although, LEACH protocol play significantly will to address the load balancing issue in IoT network, but the formation of clusters in an operational network creates network overhead specifically in LEACH protocols. Sometimes, dynamic cluster head selection with continuous rate consumes extra energy of specific sensor devices, because this device is selected as a cluster head nodes repeatedly, which leads to minimize their lifespan in the network. Consequently, some other routing protocols had been discussed in the article to address the load balancing issue in IoT networks [10]. In the case of single-hop communication, some schemes had been discussed in the literature, but once the distance between the source and base station is increased, then the energy consumption of the source node is also increased which minimizes the lifetime of a sensor device in the network [11]. Likewise, in multi-hop communication infrastructure, the sensor devices closer to the base station consumes more energy and it is easy for them to die soon as compared to other ordinary devices of the network [12]. The Energy Efficient Clustering Scheme (EECS) was designed to make the cluster formation at some distance from the base station to resolve the load balancing issue in the IoT network. The suggested scheme was failed later on, because the formation of the cluster head at a distance from the base station consumes more energy while processing the collected information of connected sensors, which minimizes network lifespan [13]. The Energy-efficient routing scheme was proposed in the article [14] to resolve the load balancing issue in IoT networks. This scheme uses the residual energy information of sensor devices to schedule traffic in the network.

Although, the suggested techniques in literature have some benefits with associated limitations to address the load balancing issue in IoT. Therefore, this field is still open for the research community to design new protocols or modify the existing protocols to resolve the load balancing issue in IoT with minimum network cost and maximum results. To resolve this issue, in this paper, we proposed an energy proficient routing scheme, which is known as Dynamic hop selection static routing protocol (DHSSRP). The proposed scheme manages the network traffic on priority based information in a congested-free communication environment to balance the energy consumption of participating sensor devices and extend network lifetime.

The proposed DHSSRP manages network traffic on priority based information and suggests an alternate route to the adjacent sensor devices for communication in the network. Moreover, to elaborate the

Table 1
List of notations used in this paper.

Notations	Description
λ	Priority class messages rate
Ft	Busy/sleep state
n_x	Active queue
x	Priority class
$P_{r(x)}$	Transmission probability of class x
m_x	s backoff state
R_{TX}	Retransmission state of class x
P_{busy}	Busy probability
(W_x,1,y)	Post backoff process
q	Probability of sensor device to transmit priority message
P_r B—l	Probability of specific busy route
τ_x	Priority time slot
S_x	Normal traffic
$P_{(r)(s,x)}$	Probability of successful transmission
L_x	Size/length of packet payload
$T_{s,x}$	Request to send for priority class x
$T_{s,x}$	Clear to send for priority class x
H	Packet header
l	Length/size of packet header
δ	Propagation delay during transmission
5(SM)	Define interval of time for five consecutive messages
E_{delay}	Expected delay
$\sigma^2_{T_x}$	Variance in packet arrival time
$A[T_x]$	Average transmission delay
B_x	Number of neighbors hop count
F(x)	Freezed hop count during priority transmission
E(R_x)	Average number of retried packets
T_{wait}	Waiting time
$Edelay(x)$	Expected delay for class x
MSB	Maximum size of the burst
$D(B_{max})$	Maximum delay bound time
DP	Data priority
ρ	Data rate during transmission
SI_{max}	Maximum service time
SI_{mini}	Minimum service time
T_xOD_{max}	Maximum opportunity transmission
T_xOD_{mini}	Minimum opportunity transmission
Rframe	Buffered frame size

concept of the proposed model, once an ordinary sensor device detects relevant activity according to their assigned task, it broadcast an alarm to acknowledge the priority of his information in the network. The neighbor's sensor devices react to the acknowledgment message by following an alternate route for communication in the network. Similarly, the message pass through route is bound for the defined interval of time, where the event of priority information exists. Likewise, this route did not advertise its hop count selection for neighbor's sensor devices until the defined interval of time specified for priority base information communication or exchange.

In converse, the adjacent ordinary sensor devices advertise and update their routing table for hop selection information to process their collected data in the network by following the shortest possible path to destination device/location. The proposed DHSSRP in this fashion manages the network traffic to minimize network overhead, avoid congestion, maximize throughput, minimize PLR, and prolong the lifespan of an individual sensor device. Similarly, the proposed model prolongs the network lifetime with balanced energy consumption.

Moreover, the abbreviation and symbol used in the paper are shown in Table 1.

The overall paper is organized as Section 2 of the paper overviews the related work, while Section 3 of the paper contains the contribution and research gap. Section 4 of the paper presents the proposed model and its mathematical structure. Section 5 of the paper overviews the implementation and captured results of the proposed model during simulation. Finally, Section 6 summarizes the paper with future work.

2. Related work

Load balancing in the Internet of things (IoT) networks with a congestion-free communication environment is one of the challenging tasks for researchers to design new protocols or modify the existing protocols to resolve this issue. In this section, the existing techniques of IoT load balancing are comprehensively overviewed with their merits and demerits.

Chien et al. [15] proposed a service-oriented SDN-SFC load balance scheme for constraint oriented networks such as IoT. They used classification parameters in their scheme to consider the communication priority of each device in the network. The limitation of this scheme is high network overhead, which creates congestion and contention during communication process. Gomez et al. [16] proposed a machine learning-based load balancing scheme, to resolve the load balancing issue in the IoT network. In the proposed model, they used both supervised and unsupervised machine learning techniques with a combination of Markov Decision Process (MDP) to resolve the aforementioned issue of load balancing in IoT networks. The proposed model improves the packet delivery ratio by reducing communication costs in the network. However, the complex model implementation need extra care with sufficient resources. Talaat et al. [17] proposed the dynamic resource allocation technique for load balancing of IoT networks. The operational method of the proposed model is based on the reinforcement learning and genetic algorithm to manage network traffic. Moreover, the proposed model continuously monitors network traffic intending to schedule balance network traffic among participating servers. The limitation of the proposed model was its emphasis to distribute load among servers not among the client with implementation for specific system.

The redundant energy consumption laxity based load balancing algorithm (RECLB) was proposed by Enokido et al. [18]. The proposed scheme uses virtual machines to effectively distribute the load among the participating sensor in the network and prolong their lifetime. The limitation of proposed scheme was the development of virtual machines with complex methodology. Moreover, this creates high E2E delay, PLR and low throughput in an operational networks. The adaptive neural fuzzy cluster algorithm (ANFCA)) for wireless network load balancing such as WSN and IoT was proposed by Kashyap et al. [19]. They synthesized the fuzzy logic in the neural network, which uses the optimal number of cluster heads to counterbalance the workload among participating sensor devices. The limitation of proposed model was contention and congestion, due to dependencies on cluster head nodes, which creates network overhead in an operational networks.

The Infrastructure as a Service (IaaS) algorithm for load balancing in IoT was proposed by Adhikari et al. [20]. They used server-based management for incoming network traffic to balance the workload between participating sensor devices. The server checks the size of the packet to allocate the best path with minimal resource utilization. The utilization of proposed model was specific to some define systems or environment. The Energy Efficient Cloud-Based Internet of Everything (EECloudIoE) load balancing scheme was proposed by RM et al. [21]. They used the two area integration paradigm to provide valuable services to the end-user with minimum energy consumption. Moreover, they used a Wind-Driven optimization algorithm for the formation of clusters in the network, which process information to the end-user with minimal energy consumption. The two area integration with Wind-driven optimization increases the complexity of proposed model for real environment implementation. Moreover, the complex communication environment degrades the performance of the network in terms of high E2E delay, PLR and low throughput. The fuzzy and unequal clustering (FBUCA) algorithm with the aggregation of a three-tier multi-hop optimized routing technique (TM-ORT) for wireless sensor network load balancing was proposed by Rajaram et al. [22]. They used the multi-hop routing protocol infrastructure to verify the reliability of data in term of QoS and energy consumption. However, the proposed model neglects the communication parameters such as communication and computation cost.

Software-defined wireless sensor network (SDWSN) architecture for load balancing of IoT was proposed by Cui et al. [23]. The proposed technique uses a centralized software-defined network (SDN) with flexible traffic management to minimize the energy consumption of participating IoT devices in the network. The author used OpenFlow protocol framework for the real traffic monitoring in the network to verify the performance. The limitation of the proposed scheme was high E2E, high communication cost, system failure with a centralized controller. In addition, SDN uses the ordinary sensor devices to sent new packet requests to the centralized controller, where the controller needs to find the path for the requesting sensor device. Then, certain rules are followed and updated on the sensor device by the controller which adds an additional delay i.e. the flow insertion and computational process. Therefore, the communication cost of the network increases in terms of latency, congestion, and contention. In addition, the failure of the centralized control plane limits the availability of the network, because the algorithm for load balancing runs on the controller.

The software-defined network framework for load balancing in WSNs and IoT was proposed by Qin et al. [24]. Furthermore, they considered the emergency control system in the urban area to verify the feasibility of the proposed scheme. The limitation of the proposed model was specific system with high implementation and maintenance cost. Amri et al. [25] proposed the fuzzy localization algorithm to resolve the load balancing issue in IoT. They used the distance parameters in their scheme to measure the data flow in the wireless channel. The limitation of proposed model was that distance parameters in wireless communication did not maintain consistency, due to fidelity and attenuation etc,. Wang et al. [26] proposed the energy-efficient compressive sensing-based clustering routing (EECSR) protocol to resolve the load balancing issue in the IoT network. The analytical model in a combination of a centralized cluster algorithm was proposed by Wang et al. [27] to resolve the load balancing issue in IoT. Although, the proposed scheme was efficient for load balancing, but they have some limitations such as complex model deployment, network overhead, etc. The Power-Aware Distance Source Routing (PADSR) clustering algorithm for load balancing of WSNs was proposed by Thirukrishna et al. [28]. The limitation of the proposed model was homogeneous environment implementation.

The battery-friendly relay selection (BFRS) scheme was proposed by Lui et al. [29], to prolong the lifespan of WSNs. They used the energy weight-based metric to select the next-hop count for message exchange in the network. However, complex computation of the proposed model generates network overhead, which affects the communication reliability of the network. Tan et al. [30] proposed the low redundancy data collection (LRDC) algorithm to address the load balancing issue in wireless networks with better E2E delay by utilizing matrix completion method. However, the complex segregation and filtration method of proposed model minimizes its use in the real deployment. The energy conserving and transmission radius adaptive (ECTRA) scheme for energy harvesting wireless sensor networks was proposed by Ju et al. [31] to prolong network lifespan. The proposed model emphasis to prolong network lifetime, but neglects the communication parameters such as packet lost ratio, throughput, and computation cost etc,.

3. Limitation of the existing scheme

Although, load balancing in IoT is a mature area for the research community, and they have proposed various techniques in the literature to resolve this issue. However, most of these techniques are either overlay complex, specific to system or complex deployment with minimal results. Therefore, an efficient load balancing scheme in IoT is still an open research area for scientist to devise new techniques or modify the existing techniques to resolve this issue in IoT networks. Moreover, it has been observed within the existing literature that most of the techniques emphasis to resolve the load balancing issue in wireless networks, but did not consider some critical aspects of the network, which are summarized below:

1. Complex scheme with high E2E delay, PLR and low throughput.
2. Specific to the system or environment.
3. High network overhead such as congestion and contention.
4. High network and maintenance costs.

Therefore, we proposed an efficient routing scheme to resolve the associated issues of load balancing in IoT.

3.1. Problem statement

An IoT network topology, which contains a set of sensor devices D_i. The ith term in D_i is used to represent the sensor devices, which is, i = 1, 2, 3, 4, …n. However, the total number of sensor devices are assumed as n in the deployed area. Moreover, it is required to design a network infrastructure for aforementioned network, which addresses the load balancing issue with priority-based traffic by utilizing minimal network resources with optimal results.

3.2. Motivation of the proposed scheme

The literature suggests various schemes to improve the lifespan of IoT networks, but most of the techniques emphasize on how to improve the load balancing of the deployed IoT network. Therefore, an efficient load balancing scheme is suggested in this research, which addresses the load balancing issue of IoT network with a congestion-free communication environment. Moreover, this scheme is very effective for those systems, which is designed for critical issues or information gathering, because its priorities specific task information in the network. The prioritization of traffic is made on the bases of priority classes, which enables all participating devices to share their collected data with remote destinations in a collision-free and congestion-free environment. The congestion-free communication infrastructure of the proposed scheme improves the latency, throughput, PLR, and individual sensor device lifetime, which ensures the effectiveness of this scheme over the existing schemes.

1. The limitation of the proposed model is its complex implementation in the initial phase or network deployment phase. In addition, when implementing this model, we need to manage the proposed model in an appropriate manner to achieve accurate results. Therefore, we consider this aspect as limitation, but in reality it ensures the performance reliability of our scheme. To elaborate, this property of the proposed model does not affect its applicability in the real deployment.
2. When the deployed sensor device detect critical information at the first attempt and transmit the message through hop count, but at the subsequent transmission there is no critical information, then, the sensor devices involved in hope count waits for define interval of time, and did not advertise their hop count information until the define time interval expires. However, this happens in an operational network very rarely.

4. Proposed methodology

Load balancing in IoT and WSNs is one of the exigent issues for the research community in the field of wireless networks. Therefore, this issue is still an open door for the researcher to devise new techniques, which can ensure the load balancing of the sensor devices with accurate results. The related work section illustrates various schemes, which had been used in the recent past to resolve the aforementioned issue of load balancing in IoT. However, some of them play significantly well in terms of load balancing, but they are at some stage limited to system, application, or environment, which can minimize its use in the real deployment of IoT networks.

In this paper, we proposed the DHSSRP routing protocol scheme, which manages network traffic in a congestion-free communication environment based on priority information with a balanced load among participating sensor devices. Moreover, the proposed model uses the acknowledgment packets of sensor devices to prioritize their traffic in the network and assign an alternate route to neighbor devices. The acknowledgment packet of sensor devices contains information such as device ID, priority time interval, route occupying time, route details, and destination address. Once the acknowledgment packet is broadcasted in the network, the other participating devices in close vicinity choose an alternate route for communication in the network. Similarly, the other participating devices of the networks advertise their route information in the network utilizing broadcast messages, except the devices they are in the priority message path. Likewise, the devices that did not advertise their route request (RREQ) are considered as busy devices in the proximity. The advertising route information is followed by neighbor's devices to transmit their collected information from source to destination location by means of an alternate route. This time in terms of the DHSSRP routing protocol called as sleep time or busy time. After, the priority traffic path allocation, the ordinary devices nearby uses an alternate route for communication while sending their collected data to the destination location. In this manner, the proposed model manages network traffic with balance energy consumption of sensor devices to prolong network lifespan with better end-to-end delay, throughput, and packet loss ratio. The payload of the message packet is shown in Fig. 1.

Example of the proposed scheme: Let assumes that D_i device $\in$ IoT network and communicating with the destination device. The D_i device detects an event in their vicinity and broadcast an acknowledgment packet in the network. The devices in the close vicinity of D_i observe, the D_i acknowledgment packet. The D_i device follows the communication path according to their routing table and transmits the collected data to the destination location or device. Similarly, the devices nearby delay their communication after D_i acknowledgment and update their routing table with an alternate route. The nearby devices use the alternate path for communication in the network. In this trend, the proposed scheme priorities network traffic with static routing for define interval of time in a congestion-free environment with balancing load consumption of participating sensor devices to prolong the network lifetime. A brief overview of the proposed model is shown in Fig. 2. Fig. 2 of the paper illustrates a brief overview of the proposed model. The ordinary sensor devices and base station (BS) connectivity are shown in the first block, where each sensor device advertises its routing information in the network, which is shown with the green line arrows. Similarly, in block 2 of the figure, a sensor device shown with orange color wants to communicate their collected data on the priority basis in the network. The route of the suggested device is also shown with orange arrows. Likewise, the route for the suggested device is bound for a defined interval of time, which we call sleep time or busy time in the proposed model. The other participating devices in close proximity are shown with green arrows, which continuously advertise their route information and update their routing table. Block 3 of the figure depicts the ordinary device's communication during the priority establish route in the network.

4.1. Proposed model implementation

In the communication environment of IoT, each sensor device has a partial idea of the network. Therefore, each device must sense the system status by an accurate mechanism to transmit data and avoid congestion with a balanced energy consumption between participating devices. The proposed scheme of the paper shown in Fig. 2 evaluates the system status to create a congestion-free communication infrastructure with the distributed load mechanism between participating sensor

Message payload				
Sequence-ID	Device-ID (source)	Route Information	One time Priority Ack	Sleep time of route

Fig. 1. DHSSRP routing protocol message packet payload.

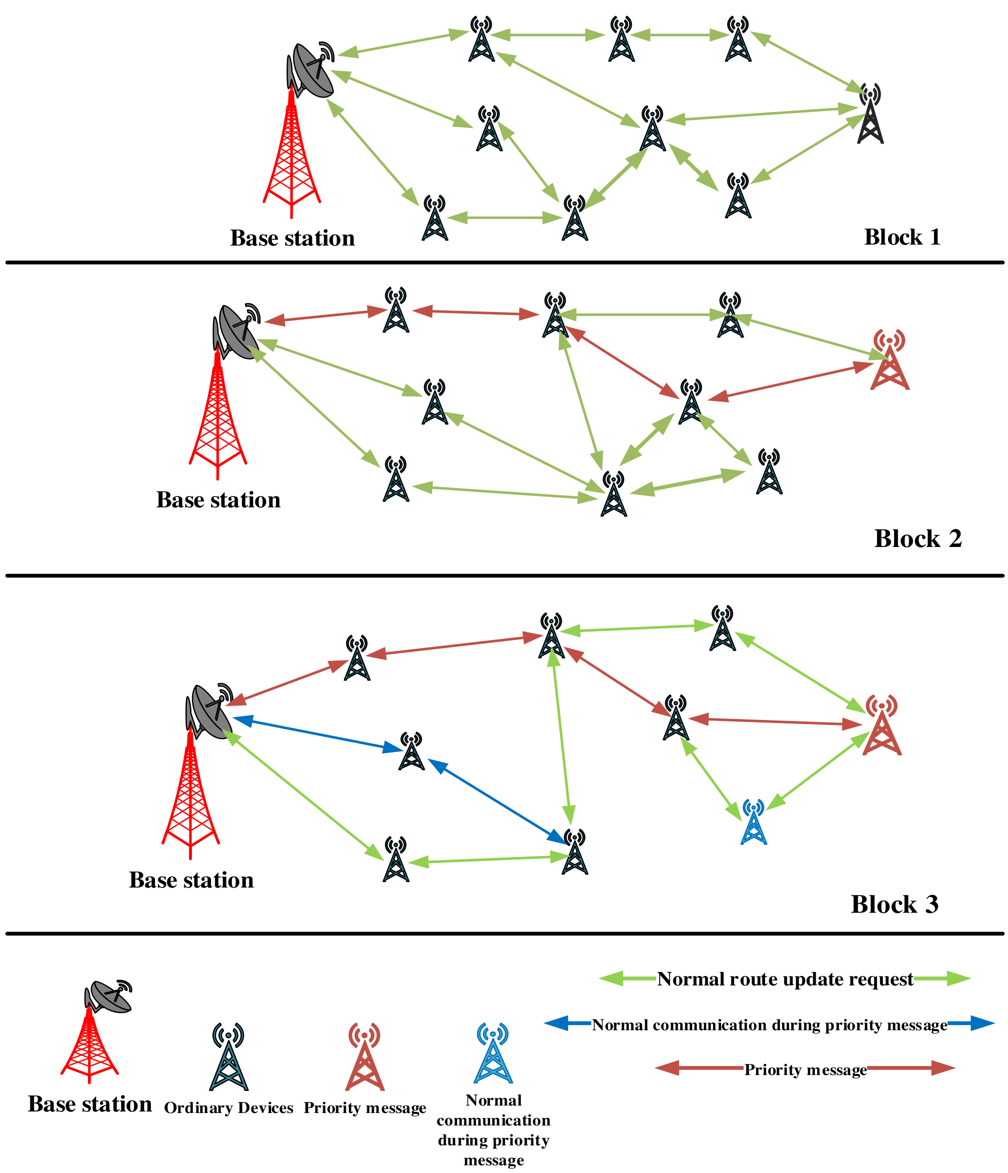

Fig. 2. Detailed overview diagram of the DHSSRP routing protocol. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

devices. The DHSSRP routing protocol uses the real-time communication data of the sensor devices to evaluate the system status. The DHSSRP routing protocol uses the route request (RREQ) and route reply (RREP) information of participating devices to schedule network traffic with accuracy, congestion-free and in a balanced load environment.

The Markov chain model [32] is used in our proposed scheme to accurately indicate or detect the system status both in saturation and non-saturation cases.

4.2. Route estimation in the proposed model

The Markov Chain Model suggests that in the proposed scheme each priority class does not have always priority data to transmit in the network. Therefore, in the proposed model the message will be considered in the priority class with the rate of (λ) messages by following the Poisson method. In addition, to utilize the DHSSRP routing protocol scheme in the model accurately, we have followed the two states allocation strategy such as idle and busy/sleep (Ft) in the system. In the idle state of DHSSRP routing protocol, there is no message in the queue to transmit. Similarly, the busy/sleep (Ft) state represents the initial communication of the message after the idle state in the network. The Post backoff (W_x,1,y) process is used to represent the empty queue of sensor device after transmission or dropping of a message frame. Suppose N is the number of priority classes in the proposed model, and nx represents the active queues in priority class (x). If the channel is clear, assumption should be non-zero transfer probabilities, as follows:

$$P_{busy} = P_r\{y, k, k|y\},\ \ y \in [m_x + R_{TX},\ 0],\ \ k \in [w_{x,y}\ - 1,\ 1] \quad (1)$$

$P_{r(x)}$ (x ∈ [N-1,0]) is the transmission probability of a sensor device with priority class x in any time slot. Moreover, m_x and R_{TX} in Eq. (1) denotes backoff state and retransmission state in class (x), respectively. Similarly, P_{busy} denotes the probability of a busy route, where the advertised hop count is busy for communication in the network.

$$1 - P_{busy} = P_r\{y,\ k+1,\ k|y\},\ y \in [m_x\ +\ R_{TX}, 0],\ k \in [w_{x,y} - 1,\ 1] \quad (2)$$

$$P_r\{k+1, k| - 1,\ \ -1\} = 1,\ \ k \in [w_{x,0} - 1,\ 1] \quad (3)$$

$$P_r\{1, 0| - 1,\ 0\}\ =\ 1 -\ P_r\ \{l| - 1\} \quad (4)$$

$$P_r\{1, Idle| - 1\}\ =\ P_r\ [l| - 1] \quad (5)$$

$$P_r\ \{0,\ 0,\ k|y\} = \frac{(1\ -\ q)(1\ -\ P_x)}{w_{x,0}},\ y \in [m_x\ +\ R_{TX} - 1,\ 0],$$
$$k \in [w_{x,0} - 1,\ 0] \quad (6)$$

In Eq. (6), q denotes the probability of a sensor device to transmit priority base information in the network by following their routing table information such as hop count from source to the destination device. Once, a sensor device transmits priority-based information in the network. The sensor device or hop count involved in the transmission process is frozen for a defined interval of time, which is five consecutive messages in our case. Similarly, these sensor devices did not advertise their hop selection information in the network for five consecutive messages in the network. In the five consecutive messages, the transmitting sensor device (priority based information) is easily identified by the administrator. However, if the delay interval exceeds the defined time limit, then the selected devices advertise their hop selection information in the network. Likewise, after five consecutive priority-based messages, the sensor devices involved in the hop count start advertising their hop count candidate-ship in the network, but at this stage, the priority-based device is identified by the administrator in the network to monitor it for further processing. Likewise, the limited resources of sensor devices are utilized efficiently in the proposed model with a balanced load, minimum computation and communication cost, least energy consumption, high throughput, least PLR, and latency.

$$P_r\{0,\ 0,\ k|m_x + R_{TX}\} = \frac{(1\ -\ q)}{w_{x,0}},\ k \in [w_{x,0} - 1,\ 0] \quad (7)$$

$$P_r\{-1, 0, k|y\} = \frac{q(1 - Pr(x))}{w_{x,0}},\ \ y \in [w_{x,0} - 1,\ l] \quad (8)$$

$$P_r\{-1, 0, k|m_x\ +\ R_{TX}\} = \frac{q}{wx, 0},\ k \in [w_{x,0} - 1,\ 1] \quad (9)$$

$$P_r\{y,\ k|y - 1\} = y \in [1,\ m_x],\ \frac{P_{r(x)}}{w_{x,y}},\ k \in [w_{x,y} - 1,\ 0] \quad (10)$$

$$P_r =\ P_r[F|l]\ = \{Ft|Idle\} \quad (11)$$

In Eq. (11), $P_r\ \{F|l\}$ symbolize the probability of hop count selection in the idle condition, while the probability busy route is represented by $P_r\ \{B|l\}$. However, the probability of hop count after priority state is represented by $P_r\ \{P_r| - 1\}$.

$$P_r\{k|Idle,\ 0\} = P_r\ \frac{B|l}{w_{x,0}},\ k \in [w_{x,o} - 1,\ 0] \quad (12)$$

$$P_r\{k|Ft, -1\} = \frac{(1 - p)}{w_{x,o}},\ k \in [w_{x,o} - 1, 1] \quad (13)$$

$$P_r\{k|Ft,\ 0\} = \frac{P_{r(x)}}{w_{x,o}},\ k \in [w_{x,0} - 1,\ 0] \quad (14)$$

The priority time slot probability for class (x) during transmission is denoted by τ_x.

$$\tau_x = \sum_{y=0}^{m_x+R_{TX}} b_{x,y,0} + P_{r(Ft)} = \frac{1 - P_{r(x)}^{m_x+R_{TX}+1}}{1 - P_{r(x)}} b_{x,0,0} + P_{r(Ft)},\ X \in [N-1, 0] \quad (15)$$

So the probability of (x) class in τ_x is:

$$= 1 - (1 - y_x)^{n_{x-1}} \prod_{y=0, y\neq x}^{N-1} (1 - \tau_y)^{ny},\ \ \ X \in [N-1, 0] \quad (16)$$

$$P_{busy} = 1 - \prod_{y=0}^{N-1} (1 - \tau_y)^{ny},\ \ \ X \in [N-1, 0] \quad (17)$$

The normal throughput for priority class (x) traffic is to be assumed as S_x (X∈[N-1, 0]). In the given time interval, the transmission probability for class (x) should be considered as $Pr(t)(RTX)$(X)(X∈[N-1, 0]). Moreover, $P_{(r)(s,x)}$ denotes the probability of successful transmission in define interval of time.

Then, we have

$$P_{r(t,R_{TX})}(X) = \tau_x(1 - \tau_x)^{n_{x-1}} \prod_{y=0, y\neq x}^{N-1} (1 - \tau_y)^{ny} \quad (18)$$

The probability with successful time slot for class X:

$$P_{r(s,x)} = n_x P_{r(t,R_{TX})}(X) \quad (19)$$

$$S_x = \frac{(P_{s,x})(L_x)}{(1 - P_{Busy})\sigma + (P_{Busy} - P_{s,x})T_{c,x} + (P_{s,x})(T_{s,x})} \quad (20)$$

In Eq. (20), L_x represents the size of packet payload in priority class (x). However, in the proposed model, the packet payload size is assumed as fixed. Our model follows the basic communication strategy of request to send (RTS) and clear to send (CTS), where values of Tc, x and Ts, x can be determined by the following equations.

$$T_{s,x}^{basic} = L + H + 2\delta + ACK + M(x) \quad (21)$$

In Eq. (21) H denotes packet header transmission time, where l is the length of payload for this time. Ack is used for an acknowledgment message in time (t), while M(x) represents the messages in priority class (x) for a defined time interval. The propagation delay during transmission of a message packet is denoted by δ.

$$T_{s,x}^{RTS} = 1 + H + 4 + 2\delta + RTS + CTS + 5(SM) + M(x) \quad (22)$$

where, 5(SM) shows priority packet busy schedules in the defined transmission time interval.

$$T_{c,x}^{basic} = l + H + 2\delta + M(x) \quad (23)$$

$$T_{c,x}^{RTS} = M(x) + RTS + \delta \quad (24)$$

G—G—1 model [33], is used in the proposed scheme to calculate the transmission and access delay for a message packet in priority class (x). However, the transmission and access delay is basically the expected delay (E_{delay}), which can be considered as the waiting and service time for a transmitted packet.

Therefore, the expected delay time for a priority class (x) packet must be met.

$$E_{(delay_x)} \leq \frac{\lambda(\sigma_{delay}^2 + \sigma_{T_x}^2)}{(1 - \lambda A[T_x]) \times 2} \quad (25)$$

In Eq. (25), $\sigma^2_{T_x}$ denotes the inter packet arrival time variance, while σ^2_{delay} represents the transmission delay for a message in priority class (x). The average transmission delay for class (x) is symbolized with $A[T_x]$.

Let B_x denotes the total number of neighbor's hop count with the priority class (x), then we get

$$E(B_x) = \sum_{count=0}^{m_x+R_{TX}} \left(\frac{P_x^{count}(1-P_x)}{(1-P^{m_x+R_{TX}+1})}\right) \sum_{delay=0}^{count} (W_{delay,x}-1) + q \times \sum_{y=0}^{m_x+R_{TX}} \left(b_{x,y,0}\frac{W_{x,-1}-1}{2}\right) \tag{26}$$

The freezed hop count for the priority class(x) is denoted by F(x) for a defined time interval, and then we have expected F(x) for a specified time interval.

$$E(F_x) = \frac{P_{Busy}}{(1-P_{Busy})} \sum_{count=0}^{m_x+R_{TX}} \left(\frac{P_x^{count}(1-P_x)}{(1-P^{m_x+R_{TX}+1})}\right) \sum_{delay=0}^{count} (W_{delay,x}-1) \tag{27}$$

The retried packet is also considered in the priority class (x) to verify the congestion-free environment of the proposed model. In addition, the average number of retrieved packets is denoted by $E(Rx)$. So, we get

$$E(R_x) = \sum_{count=0}^{m_x+R_{TX}} \frac{P_x^{count}(1-P_x)}{(1-P_x^{m_x+R_{TX}+1})} \tag{28}$$

So, the E(T_x) is given by

$$\begin{aligned} E(T_x) = {} & E(F_x)P_{s,x} \times T_{s,x} + (P_{Busy} - P_{s,x}) \times T_{count,x} \\ & + E(B_x)\delta + E(R_x)(T_{count,x} + T_{wait}) + T_{s,x} \end{aligned} \tag{29}$$

In Eq. (29), T_{wait} represents the waiting time.

So the expected delay of the packet for the priority class is to be assumed as follows to resume ordinary communication on the network.

$$E(delay_x) = E(A_{delay_x}) + E(T_x) \tag{30}$$

However, ordinary communication is continuous with an alternate route in the network, which allows the proposed model to prioritize critical information in a congestion-free network environment. Algorithm 1 of the paper shows the route estimation of DHSSRP routing protocol.

Algorithm 1 Detailed overview of DHSSRP Routing protocol for priority class traffic

Require: Allow only priority class traffic on the designated hop count/route.

Ensure: Freeze selected hop for define interval of time during priority traffic.

D_i node generates priority traffic RREQ
$D_i \in D_{n-1}$ follows $\longmapsto$ hop count information
D_i follows ← Shortest path according to their routing table
  Ordinary nodes $\in C_{n-1}$ in hop count ← D_i path freezed
    for (i=0; i = n; i++)
    where i= define interval of time to keep on D_i route freeze,
    If
    D_i (E_{delay_x}) ← $\leqq$ define time interval
    then
    Keep on Freeze route ← D_i node for time (t)
    Else
    update routing table ← ordinary nodes $\in C_{n-1}$
    Ordinary nodes $\in C_{n-1}$ ← follows routing table information for communication
  End if
End
return Current Priority class or route information.

Algorithm 1 illustrates the proposed mathematical model. An ordinary sensor device D_i initiates a priority message request with class (x) in the network. The D_i device follows the update information of their routing table to transmit the data to destination location. The D_i device packet contain priority class (x) information, which allows the next hop count devices to freeze its route for define interval to time, where D_i device collected should be shared with remote location in congestion free environment with minimum delay. When the specified time period is completed, the route advertising will continue normally and all the nodes must update their routing table for communication in the network.

4.3. Traffic scheduling with balance energy consumption based on priority information

The proposed DHSSRP routing protocol ensures the uniform load balancing of participating sensor devices in the congestion-free communication environment in terms of energy consumption and packet delay etc, in a defined bandwidth. The proposed model uses two conditions for traffic scheduling, where the first condition manages the priority class traffic and the second condition manages the normal traffic. The priority-based traffic is categorized as condition one or priority class (x), where the sensor device follows the routing table information to send their collected data to the remote destination. Moreover, the hop count sensors involved in the transmission of the process are frozen in their routing advertisement for a defined interval of time. However, the sensor device processes their normal collected data in the network. In this way, the delay in real-time priority communication of wireless networks would be decreased up to a great extent. Once, an advertised hop count route is frozen in the proposed model by priority traffic such as critical information, etc. In this case, the neighbor's devices update their routing table and follow this information to process their data in the network. Likewise, in the meanwhile of priority class (x), if any other sensor device detect critical data, then its data is transmitted with the current hop-count route as a priority class (y) and it is also frozen for define interval of time, where the neighbor's devices follow the alternate hop count for their communication in the network. In this manner, the traffic in the proposed model is managed in a congestion-free environment with a balanced load, least delay, and high throughput.

We used the super-frame time in the implementation of our proposed scheme to update the routing table of participating sensor devices. The congestion-free communication environment was developed by introducing a factor α for collision detection in the network.

So the collision rate is estimated in the proposed model by

$$P_{r(x)}(n) = \alpha P_{(r)(x)}(n-1) + (1-\alpha)P_{r(x)} \tag{31}$$

If a new priority request is initiated in the close proximity of an existing priority request, then the following steps are adopted.

1. Step 1: An ordinary sensor device ($D_i \in D_{n-1}$) initiates a new priority RREQ message in the network. The RREQ message of D_i device contains maximum delay time, expected delay time and saturation model information of the proposed scheme.
2. Step 2: The DHSSRP protocol uses the saturation model to calculate the $Delay_{max,(x)}$, throughput and τ_x. This guarantees a collision-free path in the next-hop range and freezes the route at a given time interval.
3. Step 3: The DHSSRP protocol uses the saturation model to calculate the $Delay_{max,(x)}$, throughput and t_x. This ensures the collision-free environment in the next-hop selection and frozen that route for a defined interval of time. Similarly, the vicinity sensor devices update their routing table by following the non-saturation model of the proposed scheme. The sensor devices

broadcast a packet in the network to calculate the expected delay (E_{delay}), throughput, and t_x. In addition, these devices follow the path, anticipate delay ($E_{delay(x)}$) <=$Delay_{maxi(x)}$ and saturation $S_{t,x}$ >=$S_{t,x}$, then the sensor devices follow this path as an alternative route for transmitting data from source to destination.

To allocate accurate time intervals for priority class (x) traffic it is important for DHSSRP routing protocol to be aware of current queued traffic of the network. Therefore, expected delay, time interval, and packets number are strictly followed in the proposed scheme to create a congestion-free communication infrastructure with a balanced load among participating devices. Moreover, the priority class allocation of traffic not only creates a congestion-free traffic environment, but it also enables other participating devices to advertise their shortest path hop information in the network, which balances the energy consumption of participating devices and prolongs network lifetime as a whole.

The DHSSRP routing protocol uses the priority and normal traffic control field information to manage network load. Moreover, the buffered size, traffic stream (TS), size of the queue with priority, and normal class traffic information are used by DHSSRP routing protocol to schedule traffic in a congestion-free environment. To elaborate on, the traffic scheduling is not only determined by transmission opportunities, but it also uses traffic stream information to balance network load. Therefore, it is necessary for DHSSRP routing protocol to schedule or allocate adequate transmission opportunities for all classes of messages to satisfy network traffic requirements.

We use the parameters such as the maximum size of the burst (MSB), Maximum delay bound time (DB_{max}), data priority (DP), which is from lower to high limit as 0 to 7, data rate (ρ), maximum service time (SI_{max}), minimum service time (SI_{mini}), minimum and maximum opportunity transmission such as T_xOD_{max} and T_xOD_{mini}. So we can calculate the T_xOD_{max} and T_xOD_{mini}.

$$(T_xOD_k)_{mini} = max(\frac{M_x}{R_{TX}}),\ k \in [1, N],\ x \in [1, N] \tag{32}$$

$$((T_xOD)_k)_{maxi} =< \sum_{x=0}^{N}(MSB)_\rho,\ k \in [1, N] \tag{33}$$

$$((SI_k)_{mini}) = mini(\frac{L_x}{\rho}),\ k \in [1, N],\ x \in [1, N] \tag{34}$$

Where, n denotes the transmission stream in the priority class, while N represents the number of priority sensor devices in DHSSRP routing protocol.

For transmission opportunity, the DHSSRP scheduler at a time (t_c) receives the next-hop buffer information ($R_{TX(c),x}$) for a requesting sensor device with suggestion (k). In the retransmission scenario, the transmission criteria can be satisfied by a time interval (t_c) for a new frame. Similarly, the new data will be initiated between t_c and t_{c+1}. Moreover, in the aforestated scenario, the new and lost data can be denoted consequently by $Data_{new}$ and $Data_{loss}$, because during transmission some data is lost. Therefore, we calculate the expected lost data in our proposed model during opportunity transmission. Similarly, the lost packets should be transmitted in the next transmission (T_xOD), which should be $(T_xOD)_{k,c+1}$. Likewise, for each T_xC_x, where x ∈ [0, n-1], then the new data request should be generated between $t_{c+1}\&t_{c+1,x}$ in the future T_xOD.

We have also considered the worst case for convenience with the request time information ($R_{c+1,x}$), which is equal to t_c in this case. We considered the transmission time (k) and frame deadline both at the same time for the worst condition of frame retransmission, where the maximum $((T_xOD)_k)_{maxi}$ with packet arrival time t_c for the kth transmission should be $T_{c,2+k}$. Then we have

$$\begin{Bmatrix} T_{max} =< SI_{(k)max},\ max \in [1, k+2] \\ \sum_{max=1}^{k+2} T_{max} =< (2+k)SI_{(k)max} =< (T(Delay))_{x,(max)} \end{Bmatrix} \tag{35}$$

So we get

$$SI_{max(x)} =< \frac{Delay_k - (T_xOD)_k}{2+k} \tag{36}$$

The physical bit rate for a sensor device with all load information was considered as R. The DHSSRP routing protocol frame schedule can be calculated for T_xOD during the priority packet with $((T)(Delay))_k$ as like,

$$((T)(Delay))_k = \sum_{k=1}^{n} max(C, SI_{mini(x)} + \frac{8 \times Rframe_x}{R}) \tag{37}$$

Rframe in equation represents buffered frame size of TC_x in bytes, where the overhead of MAC layer and physical layer is denoted by C.

Moreover, the scheduler of DHSSRP routing protocol to manage network traffic.

$$SI_{mini(k)} + t =< t' =< SI_{(max)(k)} + t \tag{38}$$

1. Step 1: Once, the priority-based message is initiated in the network. The scheduler of DHSSRP routing protocol starts the timer as t_{count}, to calculate the defined interval of time for priority message accurately. when the time interval of DHSSRP routing protocol expires for a priority base traffic or message, then timer reset to t_{count} zero.
2. Step 2: Similarly, the DHSSRP routing protocol scheduler continuously checks the priority-based traffic or messages in the network, to assign queue size for transmission of T_xOD with a defined interval of time to avoid congestion and collision in the network.
3. Step 3: If any Sensor device fails to transmit priority-based traffic or message with their defined queue size for consecutive cycles, then DHSSRP routing protocol scheduler reset the timer (t_{count}) to zero and waits for the next priority message in the network.

The aforementioned model represents the step by step traffic scheduling process of DHSSRP routing protocol, which manages network traffic in a congestion-free communication environment with balance load among participating sensor devices to minimizes energy consumption and prolong network lifetime. Similarly, the proposed model also improves the communication metrics such as end-to-end delay, throughput, and PLR of the deployed network.

5. Simulation set up and results analysis

The proposed routing protocol scheme was implemented in a well-known simulation tool OMNeT++, specifically designed for WSNs and IoT projects implementation. During simulation study, the viability and efficiency of the proposed model was tested to correlate outcomes with current schemes by adjusting the communication metrics. Moreover, we have the checked the performance reliability of DHSSRP routing protocol in terms of communication cost, computational cost, traffic congestion, throughput, PLR, and network lifetime to ensures effectiveness of proposed model over existing schemes. Likewise, the results statistic captured for aforementioned metrics during simulation was compared with rival schemes. The parameters shown in Table 2 was used during the implementation of the proposed scheme.

5.1. Lifetime results statistics of participating sensor device in the network

The results analysis for the proposed scheme was seen during simulation environment for ordinary sensor devices in terms of energy consumption with respect to time. The onboard battery power of participating nodes was dynamically modified to monitor the statistics of tests indicating how long the ordinary sensor devices last in the network. The results observed during simulation for proposed scheme in terms of participation of ordinary sensor devices were significant, because most of the devices were found to survive until the final

Table 2
DHSSRP routing protocol implementation parameters set up.

Parameter names	Value of the parameters
Packet size	128 Kbps
Delay bound	50 ms
Sensor devices	200, 400, 600, 800, 1000,1200
Network topology	Random deployment
Simulation environment	1200 × 800 [m]
Initial energy of nodes E_i	51,000 mAh
E consumption during sleep mode	0.75 μW
E consumption during normal state	1.3 mW
Experiment repeated for fixed sensors	7 times
Consumed E during transmission	78.6 mW
Consumed E during reception	44.6 mW
Simulation Tool/Environment	OMNeT ++
Transmission interval of nodes	18 μs
Residual energy E_r of a node	E_i - E_c
Network traffic type	UDP and CBR
Channel bandwidth	24 Mbps
Communication	broadcast
Priority class	Critical information detection
Timer update	120 μs

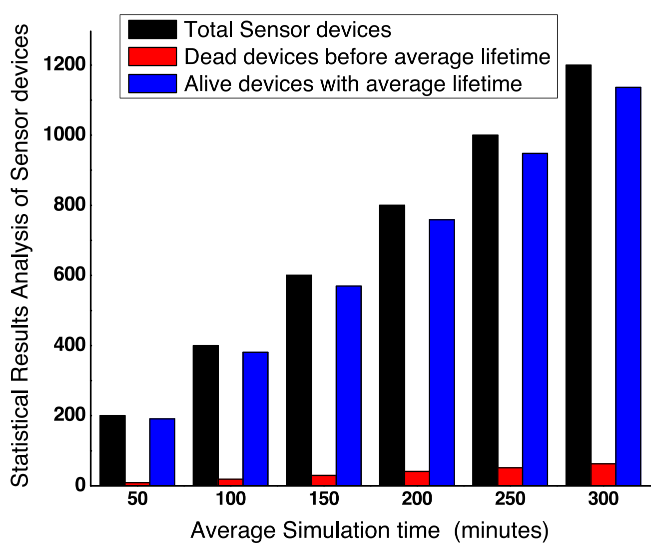

Fig. 3. DHSSRP routing protocol statistical analysis to prolong individual sensor device life time.

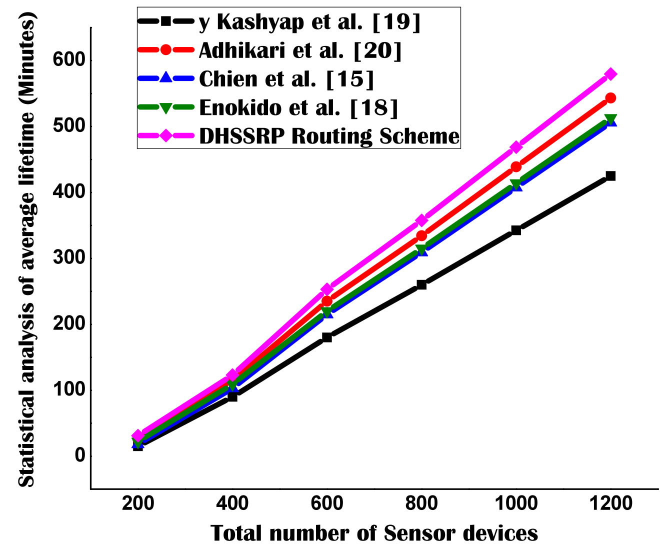

Fig. 4. DHSSRP routing protocol statistical analysis of network lifetime with rival schemes.

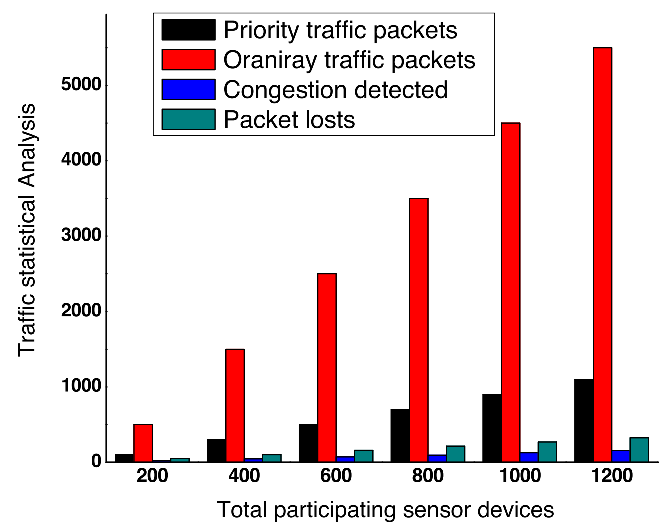

Fig. 5. DHSSRP routing protocol statistical analysis for priority based traffic.

stage of the network. The simulation results were thoroughly checked when the onboard powers of sensor devices were changed in subsequent steps. However, the DHSSRP routing protocol showed significant improvement over the existing schemes to extend the lifespan of an individual sensor node in network. The results statistics observed for participating devices in terms of energy and lifespan with respect to time are shown in Fig. 3.

5.2. Network lifespan statistical analysis with competitors schemes

The results of proposed scheme were evaluated for overall network lifespan to overview the performance reliability of DHSSRP routing protocol in presence of existing schemes. Moreover, the priority traffic was generated dynamically in the simulation environment to check the load balance management of proposed scheme in congestion-free environment to extend network lifetime. The network lifetime of proposed scheme was evaluated on the basis of average energy consumption in terms of time with its competitor's scheme. Similarly, the traffic of network was gradually increased to observe the load balancing, energy consumption of participating sensor devices and network lifetime, which was found quite convincing during simulation. The results observed for proposed scheme showed an average improvement over the existing scheme was 8%. The statistical analysis of network lifetime for proposed scheme and rival scheme are shown in Fig. 4.

5.3. Priority traffic results statistic of DHSSRP routing protocol

The results of the proposed model were also evaluated for priority class traffic to observe the collision rate for the proposed scheme. Dynamic numbers of sensor devices were activated with the priority class traffic during simulation environment. However, the sequence of activation was a little different such as with the difference of 1,2,3 messages to see the collision rate and congestion-free reliability of the proposed scheme. The results captured during simulation for consequent priority class traffic showed an average 4.5% lost ratio including collision factor. Therefore, the results were quite reliable for the proposed scheme, if, keeping in view the susceptibility factor of wireless network. Moreover, priority class PLR for proposed model was observed only 1.95%, which proves the significance of the proposed model in presence of competitors scheme to improve the quality of communication based on priority information. Moreover, the comprehensive result statistics for traffic is shown in Fig. 5.

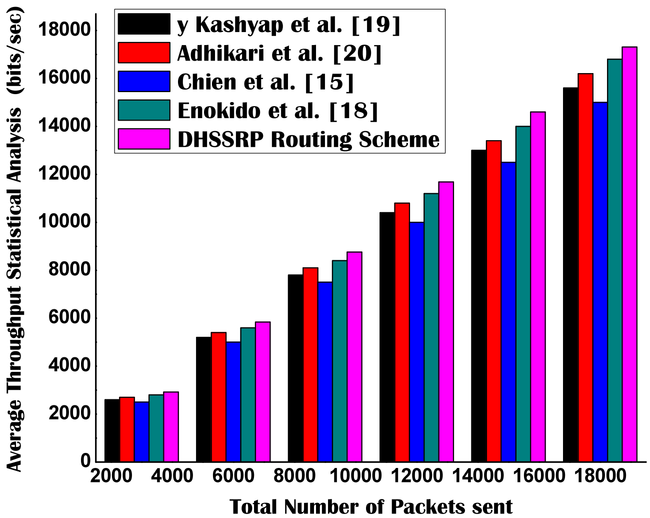

Fig. 6. Throughput statistical results analysis of DHSSRP routing protocol.

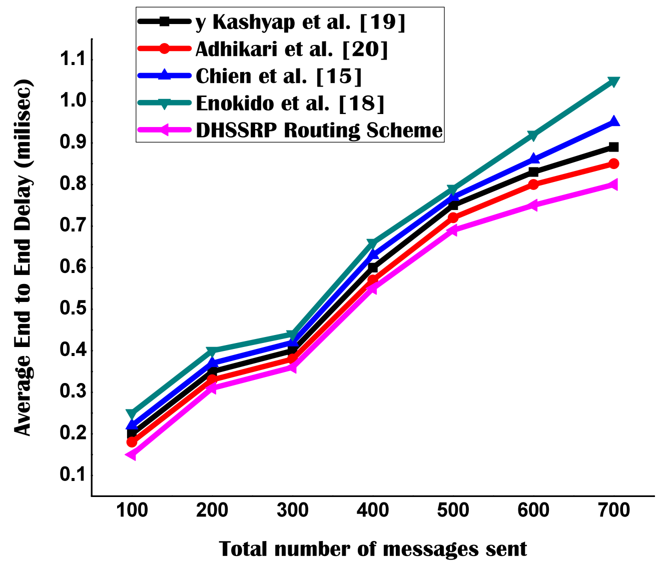

Fig. 7. End-to-End delay statistical analysis of DHSSRP routing protocol.

5.4. Throughput statistical results analysis of our scheme with rival schemes

IoT network is very effective if the communication infrastructure is reliable. Therefore, the throughput of these networks plays a vital role to share information in a contention-free and congestion-free communication environment. The results of the proposed model were evaluated for throughput because the emphasis of this scheme to share priority base information in a congestion-free communication environment. During the simulation analysis, the throughput of the proposed model was closely observed. At the initial stage of throughput analysis, the generic traffic was observed for participating sensor devices in terms of sharing data in the network with a gradual increase rate in the traffic. Similarly, the priority-based information was generated at a random rate in the network to verify the reliability factor for traffic accommodation in the proposed scheme. Although, we have increased the generic traffic of participating devices in the network during simulation, but the throughput showed consistent results for DHSSRP routing protocol. Moreover, the priority-based traffic was initiated in the network with ordinary traffic to analyze the results of throughput for our scheme. The results captured during the simulation environment for our scheme showed significant improvement over the existing scheme in terms of throughput for generic traffic as well as priority-based traffic. The statistical throughput analysis of the DHSSRP routing protocol with its competitor's scheme are shown in Fig. 6.

5.5. End to end delay results statistical analysis of our scheme

The latency results were also seen for our DHSSRP routing protocol during simulation. The latency results observed for our scheme showed consistency in terms of time for individual sensor device RREQ and RREP response. Moreover, the results statistics continuously observed by increasing the number of participating sensor device in the network. Similarly, the traffic of the network was gradually increased to see results statistics for latency. The priority based traffic was generated during latency statistical analysis to observe the ordinary sensor device traffic end to end delay. The proposed model showed quite convincing results for end to end delay during a comprehensive simulation analysis. The results statistics for our scheme in comparison with its competitors scheme are shown in Fig. 7.

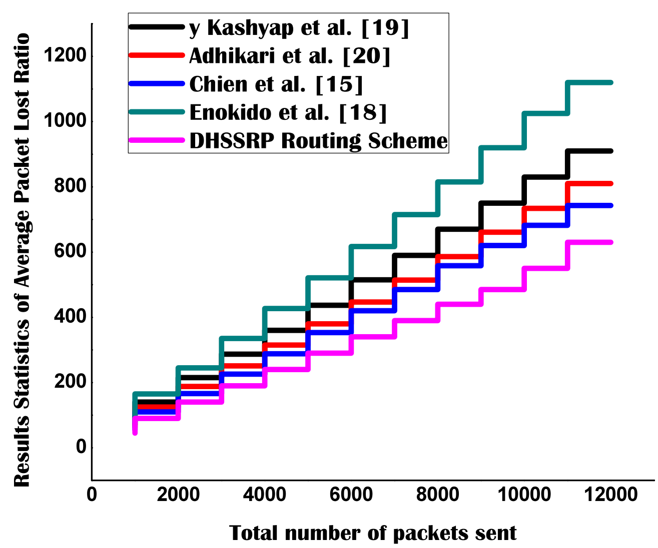

Fig. 8. Packet lost ratio results statistical analysis of DHSSRP routing protocol with its competitors schemes.

5.6. Packet lost ratio statistical analysis of our scheme with its competitors schemes

Packet lost ratio is another very important aspect to be considered in IoT because it should verify the reliability of the transmitted data in the network. The results of the proposed scheme were also checked for the packet lost ratio in the simulation environment. The traffic was randomly generated in the operational network with a continuous increased rate up-to threshold value to evaluate the packet lost ratio. Moreover, the priority class traffic was also initiated with ordinary network traffic to overview the packet lost ratio for the proposed scheme. The time duration and network traffic was continuously changed to ensure the performance of the proposed scheme. The results captured during simulation for the packet lost ratio for our scheme surpasses the rival scheme with noteworthy improvement. The results statistics for packet lost ratio of our scheme with its competitors scheme are shown in Fig. 8.

6. Conclusion

In this paper, we proposed a lightweight routing scheme to resolve the load balancing issue in IoT. The proposed routing scheme uses multi-path and multi-hop communication infrastructure to share the collected data of sensor devices in the network. Moreover, the priority-based traffic of sensor devices is managed in a congestion-free communication environment for a defined interval of time, which ensures the reliability of the DHSSRP routing scheme for the critical system, environment, and application monitoring. Although, the proposed scheme bounds the involved hop count sensor devices for a defined interval of time during transmission to share information in static routing manner, but at the same time it allows the neighbor's devices to update their routing table for an alternate route communication, which minimizes communication overhead in the network. Moreover, the proposed scheme allows the maximum sensor device to participate in the communication, which not only balances the load between participating devices, but also improves the life-cycle of an individual sensor device. In this manner, the proposed scheme prolongs the network lifetime with balanced energy consumption. Similarly, the multi-path and multi-hop communication of the proposed scheme improves the end-to-end delay, throughput, and packet loss ratio of the network, which clarifies the significance of the proposed model. The results observed for the proposed scheme during simulations in terms of load balancing, energy consumption, and communication metrics showed an average 8% improvement over the existing scheme. The participation of sensor devices observed during simulation until the end stage of the network was 95.8%, which also showed significant improvement over the existing schemes to prolong network lifetime. Moreover, the results of our scheme was also compared with competitors scheme for communication metrics such as end-to-end delay, throughput, and packet loss ratio, which surpasses the existing with an average 3%, 9% and 5% results, respectively.

In the future, we are looking to implement the proposed scheme in the real IoT communication infrastructure. Furthermore, we are also interested to extend this scheme in block chain technologies with an authentication scheme to prepare a complete package for IoT block chain networks in terms of routing protocol.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

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