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Efficiency enhancement using optimized static scheduling technique in TSCH networks

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Article Info	ABSTRACT
	In recent times, the reliable and real-time data transmission becomes a mandatory requirement for various industries and organizations due to the large utilization of Internet of Things (IoT) devices. However, the IoT devices need high reliability, precise data exchange and low power utilization which cannot be achieved by the conventional Medium Access Control (MAC) protocols due to link failures and high interferences in the network. Therefore, the Time-Slotted Channel Hopping (TSCH) networks can be used for link scheduling under the IEEE 802.15.4e standard. In this paper, we propose an Optimized Static Scheduling Technique (OSST) for the link scheduling in IEEE 802.15.4e based TSCH networks. In OSST the link schedule is optimized by considering the packet latency information during transmission by checking the status of the transmitted packets as well as keeping track of the lost data packets from source to destination nodes. We evaluate the proposed OSST model using 6TiSCH Simulator and compare the different performance metrics with Simple distributed TSCH Scheduling.

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1. INTRODUCTION

In recent times, the significance of Internet of Things (IoT) scenarios has enhanced drastically and has become one of the booming technologies which can be utilized to exchange data between objects and humans. Also, it helps to monitor the enormous amount of data in real time scenarios in various industries, several universities, organizations and healthcare applications etc. However, the integration of sensor nodes is a complex and expensive process which can be sorted out by utilizing Wireless Sensor Network (WSN) standards like IEEE 802.15.4e and Wireless Hart etc. The IEEE 802.15.4e [1, 2] standard is used in many Internet of Things (IoT) networks which employs the Time-Slotted Channel Hopping (TSCH) mode in the Medium Access Control (MAC) layer. TSCH has become a promising and very interesting topic among the various researchers all over the world due to its high reliability and packet transmission capacity. TSCH mode works under MAC protocol to ensure high reliability and low power by multiplexing in both time and frequency domain. TSCH can handle frequency of nodes in an efficient manner which is highly crucial for IoT scenarios.

Moreover, in existing TDMA enabled techniques, interference occurrence becomes an unsolved issue due to the multi-path fading and external interferences between adjacent networks. This issue can be handled efficiently using channel hopping which can transmit different packets at several channels in a synchronized manner. Therefore, a combination of TDMA and Channel Hopping can be utilized to enhance efficiency, reliability and stability [3].

However, there are some issues like node mobility, high energy consumption and high overhead which need to be addressed soon in order to maintain the performance of the TSCH networks. The mobility reduction of nodes can further led to network dis-connectivity which can initiate the functionality disruptions. Also due to high overhead, the energy consumption in the network can be drastically enhanced [4]. Therefore, in order to maintain high energy efficiency and enhance network connectivity MAC protocols must have speedy and smooth mechanism under IEEE 802.15.4e standards. The sensor nodes remain in synchronization [5] using TSCH technique and time slots are introduced in the slot frames. The sensor nodes are utilized to perform operations like transmission, reception and sleep in a scheduled way. The channel hopping ability of TSCH mode helps to avoid issues like multipath fading and environmental interference. TSCH mode enhances robustness of the network and decreases the effect of collision and enhance throughput of the network by prolonging communication range. The IEEE 802.15.4 standard operating in TSCH mode provides the basic scheduling [6] of the nodes in a network, but it does not provide schedules which can improve the low data rates, reliable communication and energy efficiency in the current industrial applications. Thus, in recent years, several researchers have presented different techniques which can increase the performance of TSCH networks and to reduce the effect of high energy consumption and overhead.

In this paper, we propose an Optimized Static Scheduling Technique (OSST) for scheduling of the nodes in a TSCH network to provide several timeslots for sender and receiver nodes based on their slot level utilization. OSST provides an effective and optimal solution in case of high traffic load when compared to any other existing techniques like simple static scheduling. This paper is organized in following sections, which are as follows. In section 2, we present related work in the field of scheduling in TSCH networks. In section 3, we describe the proposed Optimized Static Scheduling Technique (OSST) model. In section 4, we present the experimental results and performance evaluation, and section 5 concludes our paper.

2.   RELATED WORK

In [7], proposed an Autonomous TSCH scheduling mechanism for dynamic networks in which the nodes compute their schedules without any requirement of central or distributed scheduler. In [8], a TSCH technique is introduced based on Multiple Access Control (MAC) protocol to enhance the reliability and connectivity of the network. Here, the scheduling of slots is completed in a distributed way with local time synchronization. However, high delay occurs using this technique. In [9], a TSCH technique is adopted for IoT devices to improve the management of Information Centric Networking (ICN) packets. This technique will reduce the high congestion in the network and provide better connectivity. In [10], the k-cast scheduling is proposed to increase the reliability of a TSCH network by adapting a single transmitter and k receivers.

In [11], A Novel Link-based scheduling is proposed to allocate a cell for a pair of nodes in a network. In [12], the scheduling mechanism is based upon synchronization of all the nodes in a TSCH networks by incorporating a trickle timer for beacon scheduling. In [13], a novel enhanced beacon scheduling is proposed in IEEE 802.15.4e-TSCH networks which reduce the power consumption and collisions. In [14], a TSCH technique is adopted which rely upon Medium Access Control (MAC) protocols to provide better end-to-end connectivity and high reliability. This technique helps to reduce interference in multi-hop networks by balancing between the reliability and packet data delivery.

In [15], a distributed scheduling algorithm is proposed for traffic flow in all the directions in a IEEE 802.15.4e- TSCH networks. In [16], a new scheduling algorithm is proposed for resolving the conflicts in a TSCH networks by adapting a matching rule by reducing energy consumption and delay. In [17], a Poisson prediction modeling is used for scheduling in TSCH networks which reduces the end-to-end latency, overhead and queue length. In [18], a TSCH enabled scheduling technique is introduced for IoT enabled devices. Here, a QSS algorithm is adapted which reduces the quantity of information packets needed for scheduling. In [19], a TSCH scheduling technique is designed for IoT devices in an Information-Centric Networking environment which helps to avoid the error recovery issues in the ICN environment. However, it requires more delay for scheduling. In [20], Adaptive medium selection technique is adopted to reduce the delay in TSCH networks. It ensures high reliability and efficiency while delivering the data packets. |In [21], an efficient scheduling technique is adopted in TSCH networks to provide high throughput and minimum delay considering the deadline constraints. A scheduler based on genetic algorithm is proposed to provide optimal throughput and minimum complexity. However, optimization problem occurs using this technique.

In [22], focused on energy constraint in a IEEE 802.15.4e-TSCH Network to schedule the nodes by incorporating a heuristic scheduling method. In [23], an efficient scheduling technique is introduced in TSCH networks under IEEE 802.15.4 protocols to handle high traffic. It is used to estimate the high rate of

congestion to its maximum capability by enhancing the reliability and efficiency of the TSCH networks. However, the computational complexity is high using this scheduling. In [24], a centralized scheduling technique is introduced to ensure high reliability and performance in TSCH networks. This technique enhances the throughput of the network and reduces the delay problems. However, maximum weight matching and delay minimization problems may decrease the performance of the network.

In [25], the performance analysis of Orchestra is investigated for TSCH Networks used in Internet of Things (IoT) applications. In [26], a new scheme is introduced for scheduling TSCH networks by allocating Virtual slots for the nodes in a TSCH networks which doesn't require any additional reconfiguration. In [27], an autonomous scheduling mechanism is introduced to minimize the delay occurred due to packet transmission in a TSCH networks. In [28], an analytical model is proposed for TSCH-CSMA for the shared links in a TSCH networks.

3. PROPOSED OPTIMIZED STATIC SCHEDULING TECHNIQUE (OSST)
3.1. Preliminaries

In this section, the detailed modeling of Time-Slotted Channel Hopping (TSCH) technique is introduced. Let N represent the number of channels in a TSCH networks for communication. The range of this channel lies from [0, N] and every channel can be termed as a channel equalizer. For the offered time-slot and channel equalizer, various connections of pair wise type is provided to communicate with different devices. Assume that [m, channel equalizer] shows a connection between a node pair. Then, for a m timeslots with a network frequency f specific time duration can be described as,

$$f = G[(S + R) \% M_C] \tag{1}$$

Where, S can be termed as non-varied slot number and can be described as the overall time-slots exhausted from the network initiated point. Global increment method is utilized for non-varied slot number S updation at each time-slot. Therefore, it is utilized for nodes and can be termed as timeslot counter. Here, R can be termed as channel equalizer whereas C denotes the channels utilized in the network. Here, G can be described as a lookup table function. Furthermore, equation (1) shows a channel hopping method which provides varied frequency for a varied time-slot in a single link. This verifies that any available channel can be utilized from the network link to communicate between devices. Basically, TSCH scheduling technique offers two dedicated links namely single and shared links. Shared links possess a vital role in TSCH scheduling due to their routing and scheduling data transmission to other destination, also to reduce the repetitive collision probability.

3.2. Modeling of time-slotted channel hopping with collision avoidance (TSCH-CA)

This section provides modeling of TSCH-CA Algorithm which decreases the repetitive collision probability in case of a shared links in TSCH networks. A sender node t transmits an information packet to the receiving node n over a shared link (t, n). The sender node t transmits the consecutive information packets, once the first information packet is reached to the destination. Thus, collision avoidance algorithm is introduced to decrease the repetitive collisions. The following steps need to be followed to have an efficient TSCH-CA [28] technique.

a. A state variables group need to be initialized like total iterations required for proper re-transmissions for the current frame $(I = 0)$ and exponent E.
b. An arbitrary constant $v \epsilon [0, 2^E - 1]$ is introduced.
c. The data packets which need to be re-transmitted on v shared channels can be delayed till the dedicated link is experienced.
d. If the data packets are re-transmitted on v shared channels successfully then E can be set as $J_{d_\downarrow}(E)$ and the process can be finished. In case, the data packets transmission becomes unsuccessful then the state parameters can be updated as follows, $I = I + 1$ and $E = \min(E + 1, J_{d_\uparrow}(E))$. At last, if the total retransmissions become larger than the threshold value $(I > J_{d_\uparrow}(E))$ for the present frame then the data packets can be released or the second step can be repeated again.

Here, the energy required for the transmission and reception of data packets can be denoted as F_t. Then, the power required for the transmission to reception of data packets can be expressed as $Q_{ky}(Q_{ny})$. Here, data acknowledged sensing time is denoted as $B_{ky}(B_a)$. Therefore,

$$F_{Y_{k,y}.Y_{k,x}+1} = m.F_t \tag{2}$$

Where $F_{Y_{k,y}.Y_{k,x}+1}$ represents the stored energy from state Y_{kx} to the consecutive state $Y_{kx}+1$. Here, F_t can be described as,

$$F_t = Q_{ky}. B_{ky} + Q_{ny}.B_a \tag{3}$$

Then, the estimated probability $H(e)$ of weak connections $e \in A_i(D_i)$ can be expressed as where $A_i(D_i)$ is the group of total weak connections in the network of nodes D_i,

$$H(e) = \left(e_{L_{i+1}} e_{P_{i+11}} \dots \dots e_{P_{i+1}v_{i+1}-1}}^{D_i} \right) . ((V_{i+1})^{-1})^{D_i} \tag{4}$$

Where, $\left(e_{L_{i+1}} e_{P_{i+11}} \dots \dots e_{P_{i+1}v_{i+1}-1}}^{D_i} \right)$ represents the coefficients of multinomial. Here, L_i and P_{i+11} represents the states of nodes whereas V_{i+1} denotes transmission states of $i+1$ trials. The state L_i can be utilized for next transmission. In equation (4), the second term can be expressed as the probability of occurrence of every trial. Then, stochastic network transition A_i can be expressed as $A_i = \{e_0, e_1, \dots, e_{\uparrow N-1}\}$. Whenever, failure occurs in nodes D_0 transmission in state L_0, similarly failure occurs in nodes D_1 transmission in state L_1 and so on, then the stochastic set φ_{A_i} for each stochastic network transition A_j can be expressed as,

$$\varphi_{A_i} = \mathop{\mathcal{G}}_{i=0}^{\uparrow N-1} A_i D_i \tag{5}$$

Then, the stochastic network transition $A_j \in \varphi_{A_j}$ probability $Q(A_j)$ can be expressed as,

$$Q(A_j) = \prod_{i=1}^{\uparrow N-1} H(e_i) \tag{6}$$

Where, $Q(A_j)$ can be obtained using (4). The occurrence of stochastic network transition $A_j \in \varphi_{A_j}$ can progress in next stage. Moreover, the energy $F_{Y_{k,y}.Y_{k,x}+1}$ required for the transmission from one state to next state can be expressed in the following equation,

$$F_{Y_{k,y}.Y_{k,x}+1} = m.F_e \tag{7}$$

Where, transmission energy F_e can be expressed as,

$$F_e = Q_{ky}. B_{ky} + Q_{ny}.B_{ko} \tag{8}$$

Where, B_{ko} can be described as the connection timeout. Then, the energy $F_{Y_{k,y}.Y_{k,x}+1}$ required for the transmission from one state to next state, when only one node successfully transmit its packets and the other $(m-1)$ nodes experience failure in packet transmission,

$$F_{Y_{k,y}.Y_{k,x}+1} = F_t + (m-1).F_e \tag{9}$$

Assume that, compression energy evaluation occurs with estimated probability $Q_{CE}(m)$. In all m receiving nodes, the node l send its data packets successfully and changes to state T and every remaining node $m-1$ failed to transmit due to failure and need to resend again. Our proposed model has total $N+1$ conditions which belongs to each possible state of node l i.e. $L_0, L_1, \dots, L_{\uparrow N}$. Assume that, the transmitted node l lies in the state $L_y (0 \leq y \leq \max \uparrow)$. Then, the probability of node l in state L_y at time k_x can be determine as when $\sum_{y=0}^{\uparrow N} Q_{\mathbb{CE}}^y = Q_{CE}(m)$,

$$Q_{CE}^y = Q_{CE}(m).\left(Y_{k_x}[L_y].(m)^{-1} \right) \tag{10}$$

Where, the node l changes to state T, then the remaining node $Y_{k_x}[L_y] - 1$ nodes remains in state L_y. Moreover, the nodes present in state L_z where $z \neq y$ receives a sending failure. Then, $f_y = Y_{k_x}[L_y] - 1$, where $f_z = Y_{k_x}[L_z], z \neq y$. Moreover, the energy consumed by TSCH network can be denoted as $F_{Y_{kx}.Y_{kx}+1}$, where its states changes from Y_{kx} to $Y_{kx}+1$. The (11) states that only one node transmits its packets and other remaining nodes $m-1$ fails to send packets. Therefore,

$$F_{Y_{kx}.Y_{kx+1}} = F_t + (m-1).F_e \tag{11}$$

Where, probability matrix of transition, for every couple state (Y, X) and $(Y, X) \in G_t$. Here, Q_{YX} represents the probability of network state which alters from Y to X state and k_x to k_{x+1} time. Similarly, F_{YX} can be defined as the energy consumed by TSCH network when the states changes from Y to X state. From the above equations, we define

e. Packet Transportation Probability($\bar{B}$): the ratio of accurately received information packets by node n to the overall transmitted data packets.

f. Average information packet latency($\bar{W}$): The average time needed from the initial point to final point in transmitting information packets by node n.

g. Energy Consumption Occur ($\bar{F}$): The total energy occurred from initial point to final point in transmitting information packets by all the nodes in TSCH network.

h. $Q_d(k)$: The probability of receiving at least d information packets till timeslot k by the node n.

The Packet Transportation Probability($\bar{B}$) of state Y_f^i can be determined as,

$$\bar{B} = (M)^{-1} \sum_{i=0}^{M} i . \mu W_\uparrow [q_i] \tag{12}$$

Where, the probability vector can be denoted as $\mu W_\uparrow = \mu_0(Q^{W\uparrow})$ from $W_\uparrow$ to k_0 timeslots. Then, the probability of correctly received information packets during time-slot k can be defined as,

$$Q(k) = \sum_{i=0}^{M-1} Q\{\varphi_{t_i}^k\} \rightarrow Q\{\varphi_{t_{i+1}}^{k+1}\} \tag{13}$$

Where, the correctly packet transmission probability in the network from i to i+1 state can be expressed as $Q\{\varphi_{t_i}^k\} \rightarrow Q\{\varphi_{t_{i+1}}^{k+1}\}$ in the time-slot k. Then,

$$Q\{\varphi_{t_i}^k\} \rightarrow Q\{\varphi_{t_{i+1}}^{k+1}\} = \begin{cases} Q\{\varphi_{t_{i+1}}^{k+1}\} \\ -\left[Q\{\varphi_{t_{i+1}}^k\} - Q\left\{\varphi_{t_{i+1}}^k \rightarrow \{\varphi_{t_{i+2}}^{k+1}\}\right\}\right] & \dots\dots if\ p < M-1 \\ Q\{\varphi_{t_{iM}}^{k+1}\} - Q\{\varphi_{t_{iM}}^k\}, \dots\dots\dots\ if\ i = M-1 \end{cases} \tag{14}$$

Here, the (13) can be defined as the probability of successfully packet reception at timeslot k which is same as the probability of effective events in the network from slot k to $k+1$. Therefore, $Q(k)$ can be defined as the summation of each probability in the time-slots k to $k+1$ and the number of completed events in the network from i to $i+1$. Moreover, $Q(k)$ can be termed as weights and average latency of information packets ($\bar{W}$) can be described as in time-slot k,

$$\bar{W} = \sum_{k=0}^{W_\uparrow} k. Q\ (k).\left(\sum_{k=0}^{\bar{W}_\uparrow} \mathbb{Q}(k)\right)^{-1} \tag{15}$$

Where, $k \in [0, Q_\uparrow]$ and the average energy ($\bar{F}$) required by M transmitting nodes to transmit information packets using the optimized static scheduling technique can be expressed as,

$$\bar{F} = \delta_Y = \sum_{X \epsilon G_t} Q_{YX} . (F_{YX} + \delta_X) \forall\ Y \in G_t \tag{16}$$

Where, $\bar{F}$ is the total energy required by the TSCH network to reach the state Y_f^i where $0 \le i \le M$ and initiating from the state $Y \epsilon G_t$. Then, at last, the probability of receiving at least d data packets from node n in initial timeslot k can be denoted as $Q_d(k)$ and expressed as follows,

$$Q_d(k) = \sum_{i=d}^{M} Q\{\varphi_{t_i}^k\} \tag{17}$$

3.3. Simple distributed TSCH scheduling (default)

Let E represent a set of all schedules in a TSCH network. Let variable $\chi(t, n) \in E$ represent a data transmission schedule e and $\xi(t, n)$ represent the actual schedule at t^{th} slot on n^{th} channel. The scheduling in TSCH networks can be defined as $\sum_{\xi(t,n) \in E_0} c(\xi(t, n)) = 1$, where $E_0 \subseteq E$, $c(\xi(t, n))$ is the probability of $\xi(t, n) \in E_0$ and c is used as heuristic in order to satisfy the condition. Data transmissions are carried out over a set of links $L_{c,n}$. Let's consider the ith link over which data transmission is active (state of link is active) i.e. $L_{c,n}(i)$ with a probability $Q_{i,n}$. Inactivity state of the ith link is $L_{c,n}(i)$ with a probability $1 - Q_{i,n}$. The simple distributed (default) TSCH scheduling algorithm is described below.

Algorithm 1: Simple distributed (Default) TSCH Scheduling [6]

1:	Input: No of nodes, Links
2:	Output: Link Schedules, Transmitter/Receiver Slots
3:	Begin
4:	Based on channel information select a schedule $\xi(t,n) \in E_0$ with probability $c(\xi(t,n))$.
5:	If no $L_{c,n}(i)$ links were active in earlier data slot,
6:	state $\chi_i(t,n) = 1$ with $Q_{i,n}$ probability
7:	state $\chi_i(t,n) = 0$ with $1 - Q_{i,n}$ probability
8:	else
9:	state $\chi_i(t,n) = 0$
10:	end if
11:	If $\chi_i(t,n) = 1$, then associated link will transmit/route an assigned packet in data slot.
12:	end if
13:	end

3.4. Proposed optimized static scheduling technique (OSST)

The Simple distributed (default) TSCH Scheduling considers only channel state information in scheduling. Proposed OSST considers packet latency information $(\overline{W})$ to control the backoff time in addition to channel state information. Packet collisions are minimized using packet latency information over links in OSST. If link latency information is included in schedule, then it can control the data-slot based carrier sensing information and optimized slot assignment, leading to improved throughput.

Algorithm 2: Optimized Static Scheduling Technique (OSST)

1:	Input: No of nodes, Links
2:	Output: Link Schedules, Transmitter/Receiver Slots
3:	Begin
4:	Initialize Backoff time for i^{th} link B_i such that $0 < B_i < \overline{W} - 1$.
5:	If data is available for transmission over $L_{c,n}(i)$ prior to $\mathbb{B}_i + 1$ time slot then it is not included in schedule $\xi(t,n)$
6:	Set i^{th} link state is to $\chi_i(t,n) = \chi_i(t-1,n)$
7:	If channel is free based on channel state information and no data is there over $L_{c,n}(i)$ prior to $B_i + 1$ time slot, slot assignment message is broadcasted
8:	If packet is dropped or collision occurs, i^{th} link state is set to $\chi_i(t,n) = \chi_i(t-1,n)$ and inclusion in $\xi(t,n)$ is not considered.
9:	If slot assignment is successful, i^{th} link is included in $\xi(t,n)$ and transmission state is updated as follows
10:	If no $L_{c,n}(i)$ links were active in earlier data slot then
11:	state $\chi_i(t,n) = 1$ with $Q_{i,n}$ probability
12:	state $\chi_i(t,n) = 0$ with $1 - Q_{i,n}$ probability
13:	else
14:	state $\chi_i(t,n) = 0$
15:	end if
16:	end if
17:	end if
18:	end if
19:	end if
20:	If $\chi_i(t,n) = 1$, then associated link will transmit/route an assign packet in data slot.
21:	end if
22:	end

4.   PERFORMANCE EVALUATION

This section describes about the performance of the proposed Optimized Static Scheduling Technique (OSST) for various parameters namely Efficiency, Energy Consumption, Throughput, and packet transfer rate. The proposed OSST model outperforms the default scheduling mechanism in TSCH networks. An open source 6TiSCH Simulator is used to simulate the TSCH networks with parameters listed in the Table 1 and simulated on 64-bit windows 10 OS with 16 GB RAM which contains an INTEL(R) core i5 processor.

Table 1. Simulation parameters

Parameter	value
Frame Size	100 slots
Simulation Iterations	100 times
Maximum Resend packets	8
Maximum queue length	8
Total Transmitting Nodes	4
Total allocated Slots	10
Transmission data rate acknowledged	92.6
Reception data rate acknowledged	96.3
Maximum Utilization Threshold	0.9
Minimum Utilization Threshold	0.8
Traffic Rate	5
Reception Probability	0.9

Here, Figure 1 demonstrates the successful packet transmission comparison between the default scheduling and the proposed OSST model for different transmission rates in Mbps. From the Figure 1 it is clearly visible that default scheduling can perform satisfactory for lower transmission rate. However, for higher transmission rate, this technique is highly insufficient. On the other hand, the proposed OSST model performs far better for all the transmission rates. Figure 2 demonstrates the throughput of the network for the default scheduling and proposed OSST model for different transmission rates in Mbps. It is clearly visible that throughput of our proposed OSST model is much higher than the default scheduling for the different transmission rates.

Figure 3 demonstrates the number of successful packet transmission using the default scheduling and the proposed OSST model considering total number of packets transmitted. From Figure 3 it is clearly visible that successfully transmitted packets are more from total transmitted packets using proposed OSST model than default scheduling. Figure 4 demonstrates the number of packets dropped out of total number of packets transmitted using the default scheduling and proposed OSST model. Using the default scheduling technique the numbers of dropped packets are very high in comparison with total transmitted packets and number of dropped packets increases with the number of transmitted packets. However, the number of dropped packets using the proposed OSST model is minimum.

Figure 5 demonstrates the energy consumption in (mJ /reliable packets) using default scheduling and the proposed OSST model considering total number of packets transmitted. It is clearly demonstrated from Figure 5 that energy consumption is much higher using default scheduling technique than the proposed OSST model. Thus, in terms of energy consumption, proposed OSST model is much superior. Figure 6 demonstrates the energy consumption in (mJ /reliable packets) using the default scheduling and proposed OSST model for the different transmission rates. The energy consumption is much higher for lower transmission rates and low for higher transmission rates using the default scheduling whereas energy consumption using the proposed OSST model is very low for all transmission rates. This verifies the superiority of the proposed OSST model in comparison with the default scheduling mechanism.

Figure 7 demonstrates the idle packets present for the default scheduling and the proposed OSST model considering total number of transmitted packets. Here, the proposed OSST model consists of large number of idle packets compared to the default scheduling mechanism. Similarly, Figure 8 demonstrates the pending packets present for default scheduling and the proposed OSST model considering the total number of transmission packets. Here, the numbers of pending packets needed to transmit are more using default scheduling when compared to the proposed OSST model. Figure 9 demonstrates the energy saved in joule using default scheduling and proposed OSST model considering the total number of packets transmitted. The proposed OSST model can save enormous amount of energy in joule, especially considering higher number of packet transmission.
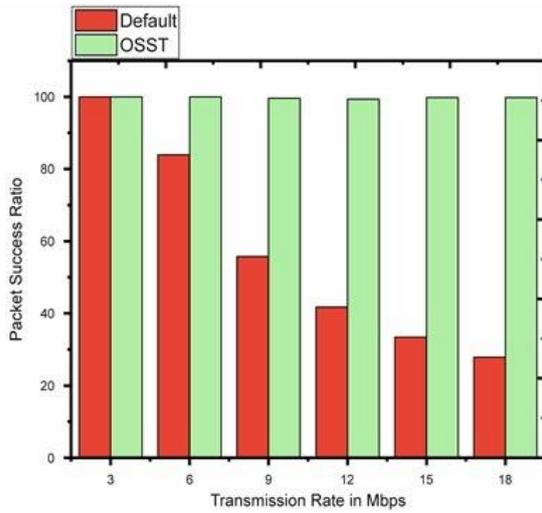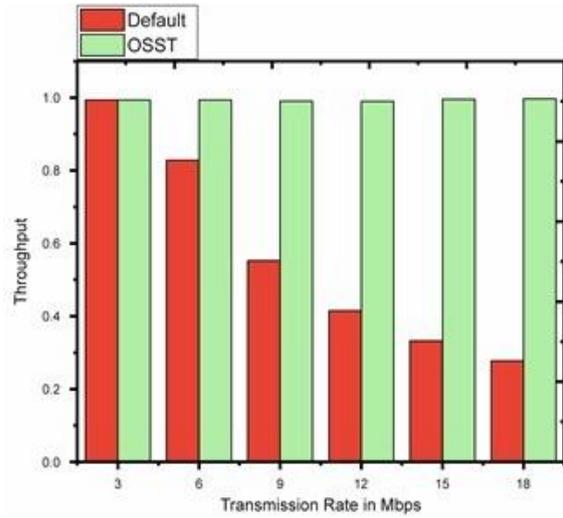
Figure 1. Packet success ratio
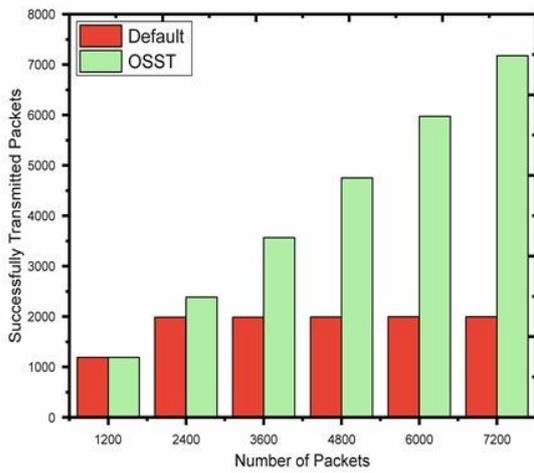

Figure 2. Throughput

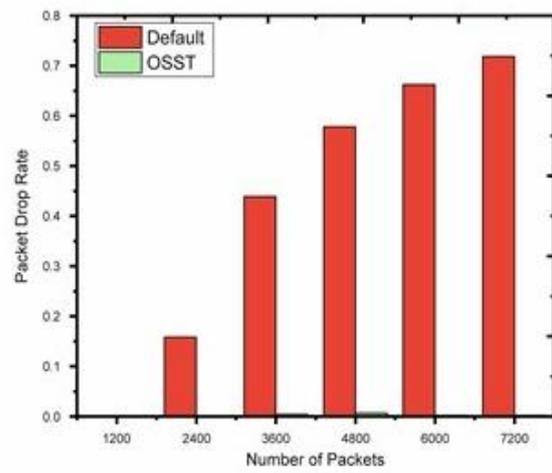Figure 3. Successfully transmitted packets

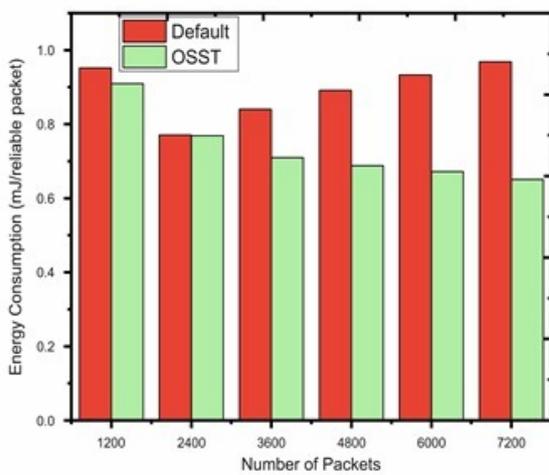Figure 4. Packets drop rate

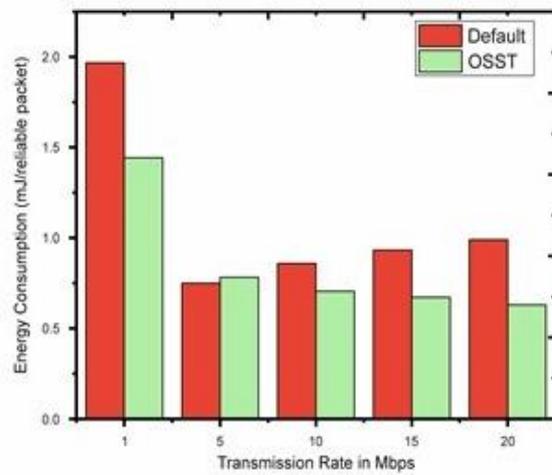Figure 5. Energy consumption with no of packets

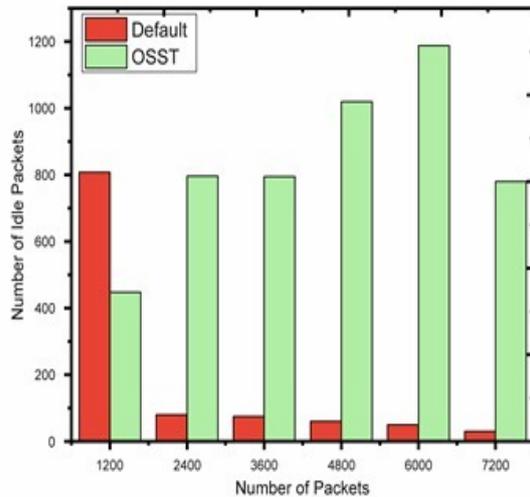Figure 6. Energy consumption with transmission rate
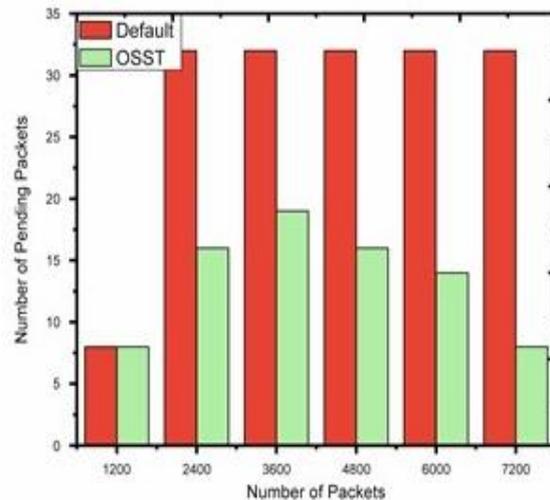
Figure 7. Number of idle packets figure

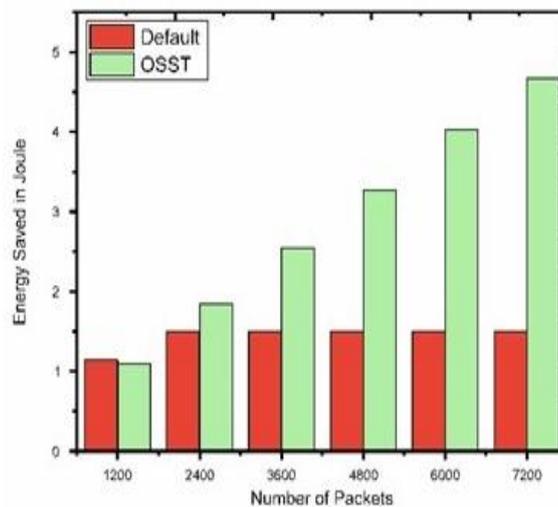Figure 8. Number of pending packets

Figure 9. Energy saved in joule

5. CONCLUSION

IoT based developments have witnessed tremendous growth in recent times. Reliable and accurate data transmission in IoT devices can be achieved using IEEE 802.15.4e based TSCH networks. The significance of Time- Slotted Channel Hopping (TSCH) networks is extremely high under IEEE 802.15.4e standard for MAC protocols due to its high reliability, throughput and stability. To further improve the network performance, we proposed an Optimized Static Scheduling Technique (OSST) for link scheduling in IEEE 802.15.4e based TSCH networks. The proposed OSST model outperforms better when compared to the Simple distributed scheduling mechanism in terms of Energy Efficiency, Throughput, Packet success ratio, Packet drop rate for the different transmission rates.

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