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Modeling and Optimization of DSME-Guaranteed Time Slot Allocation in IEEE 802.15.4e Networks based on Traffic Model

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Abstract

The advancement in Internet of Things (IoT) technology has gained more interest for the development of smart technologies. Intuitively, a wireless sensor networks (WSN) enabled with low-rate data communication can be employed in smart technologies. However, the WSN employed for these technologies should meet the basic requirement for efficient communication among the nodes. The IEEE 802.15.4e standard operating in Deterministic and synchronous multichannel extension (DSME) mode can be adopted in WSN to enable multichannel data communication between the nodes. In this paper, an optimized DSME-guaranteed timeslot allocation (GTS) allocation algorithm is developed for WSN depending on the requirements such as bandwidth, delay, throughput, and network traffic. Furthermore, the algorithm is analyzed with performance parameters associated with the WSN. Finally, the proposed model is simulated using MATLAB 2023a programming tool.

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Keywords: Wireless Sensor Networks, IEEE 802.15.4e, DSME, GTS.

1 Introduction

The IEEE 802.15.4 is a standard suitable for low-rate wireless personal area networks (LR-WPAN) with a 2.4 GHz signal transmission. The IEEE 802.15.4 standard is suitable for low-power data transmission in wireless sensor networks (WSN). Moreover, the standard is defined for the medium access control (MAC) layer in LR-WPAN. However, the standard has some limitations such as reliability, robustness, and multi-hop communication in WSN (Fanucchi et al., 2015; Lee & Chung, 2016). Wireless body area networks (WBAN) utilize the IEEE 802.15.4 standard in wearable devices for human health monitoring (Khanafer et al., 2024; Mkongwa et al., 2023). Furthermore, some additional features were incorporated into the existing standard by the IEEE working group and renamed it as IEEE 802.15.4e standard (Giji Kiruba et al., 2023). Basically, the IEEE 802.15.4e standard operates in various modes of operation to enable synchronization among nodes in a network. The first mode operates in time slotted channel hopping (TSCH) to ensure the transmission of data packets to achieve high reliability in WSN (Bommisetty & Venkatesh, 2022; G. Cena et al., 2023; Kim et al., 2024; Vera-Perez et al., 2021). The second mode operates in low-latency deterministic network (LLDN) to provide low latency for industrial applications (Pereira et al., 2022). Lastly, the third mode operates in deterministic and synchronous multichannel extension (DSME) to ensure the multichannel data transmission in WSN (Choudhury et al., 2021; Kurunathan et al., 2019; Alamos et al., 2022). In addition, the DSME mode of operation can be utilized for traffic-adaptive networks thereby extending the contention-free period (CFP) during channel allocation (Lee et al., 2021; Asuti & Basarkod, 2021).

DSME mode incorporates additional features that find extensive applications in smart metering, smart homes, health monitoring, and industry automation (Kostler et al., 2016; Kauer et al., 2016). DSME incorporates the multichannel feature for data transmission that enhances the reliability of the network (Capone et al., 2014). In particular, the DSME mode of operation adopts the DSME-guaranteed time slot (GTS) allocation scheme for enabling the multichannel feature for data transmission in WSN (Hwang & Nam, 2014). In addition, the DSME mode of operation provides a stable communication link for the nodes in WSN (Chen et al., 2013).

In WSN (Taneja., 2015; Alderisi et al., 2015; Kauer et al., 2018; Sw & Ki 2014; Sahoo et al., 2017), the algorithms were developed for congestion-free channel access mechanism operated in DSME mode (Uchida et al., 2017). However, the channel access mechanism needs to be optimized depending on the traffic congestion in the WSN. It is necessary to adopt an optimized DSME-GTS allocation scheme for such networks (Basnet et al., 2019). This motivates us to employ an algorithm that optimizes the DSME-GTS allocation to achieve congestion-free channel access mechanism (Ibrahim & Shanmugaraja, 2023). The main contributions of the paper are as follows:

- An optimized DSME-GTS allocation algorithm is developed for IEEE 802.15.4e-based networks depending on the requirements such as bandwidth, delay, throughput, and network traffic.
- Analyzes of performance metrics such as throughput, energy consumption, packet delivery ratio, reliability, packet loss ratio, and end-to-end delay.
- Validation of the proposed methodology in MATLAB 2023 a programming tool.

The rest of the paper is organized as follows, section 2 formulates the problem statement, section 3 provides the related works, section 4 provides the overview of DSME, section 5 introduces the proposed methodology, section 6 provides performance analyzes of the proposed methodology, section 7 provides the performance evaluation, Finally, the conclusion is provided in the last section.

2 Problem Statement

A WSN employed with IEEE 802.15.4e standard operating in DSME mode of operation is considered for channel allocation and data transmission among the nodes. Moreover, the end devices, coordinator nodes, and single personal area network (PAN) coordinator node are considered for network formation in WSN. The network operates in the DSME mode of operation. The end devices employed in the network sends the DSME-time slot request signal to establish the communication between the nodes. However, the network scenario may vary depending on the network size, bandwidth available, and the traffic conditions of the network. The problem statement is defined for checking the availability of DSME-time slots and allocating them for end devices to establish communication with other devices. Figure 1 illustrates the problem statement for DSME-time slot allocation process in WSN. The equation (1) as follows:

$$\begin{gathered}\text{Slot Allocation= Accept the DSME-Request } (R_A, R_C) \\ \text{At Node\_B= Process the DSME-Request } (R_A, R_C) \qquad (1) \\ \text{based on Delay, Bandwidth, Throughput, Network Traffic}\end{gathered}$$

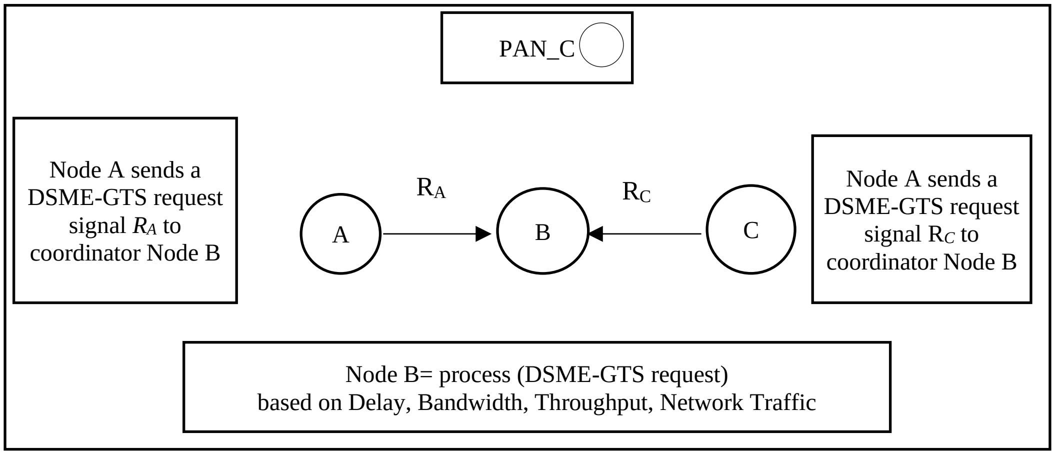


Figure 1: Illustration of Problem Statement for DSME-time Slot Allocation Process in WSN

3 Related Work

Alsudany et al., (2018) introduced three enhanced methods for DSME mode of operation in WSN. In first method, the energy consumed by the nodes is reduced by employing the wake-up command execution and control bit operation. In second method, the network association time is reduced by employing an appropriate channel access scheme. In third method, the time required for network discovery is reduced with the adoption of a channel access scheme. However, all three methods need to maintain a proper synchronization for channel allocation and extra overhead on nodes for wake-up command execution.

Vallati et al., (2017) investigated the network formation in DSME mode and optimized the performance of protocol with an enhancement in the resource and energy of WSN. Finally, the DSME mode performance was tested using contiki platform. However, the DSME-GTS allocation was not given much importance during channel allocation. Kauer et al., (2017) discussed the novel framework employed for analyzing the WSN. The framework is open access and adopted for DSME mode of operation during channel allocation in WSN.

Kurunathan et al., (2017) studied the behavior of different MAC schemes utilized for channel allocation in WSN. The first scheme was employed in TSCH mode of operation that incorporates less delay for channel allocation. Furthermore, the second scheme was employed in DSME mode of operation that meets the critical requirements in industry applications. Finally, the third scheme was employed in LLDN mode of operation that meets the low latency requirements in WSN. Juc et al., (2016) investigated the functionality of TSCH and DSME mode employed in WSN. Furthermore, the performance of TSCH and DSME was analyzed in terms of energy consumption and delay that occurred during the data transfer mechanism in the network. Finally, the authors compared and estimated the TSCH and DSME mode of operation in terms of energy consumption.

Sahoo et al., (2017) presented a novel DSME structure to study the behavior of data packets collision in WSN. In particular, the DSME structure was developed to study the hidden nodes in the network. Kurunathan et al., (2018) developed a model for multi-superframe tuning of DSME structure employed in WSN. Furthermore, the scalability of WSN was improved with the incorporation of CAP reduction in DSME mode. Gomes et al., (2017) explored the channel hopping and channel adaptation schemes in DSME mode of operation. Both the schemes were analyzed for unicast packet transmission in WSN.

Kurunathan et al., (2018) presented the integration of routing protocol with the DSME mode employed in WSN. Moreover, the integration of two protocols leads to an improved quality of service (QOS) requirement in WSN. Furthermore, a GTS allocation algorithm was developed for channel allocation that exhibited the superior link connection among the nodes in WSN. Khan et al., (2013) estimated the delay and packet delivery ratio (PDR) of WSN for different network topologies.

Alvi et al., (2019) incorporated a higher number of GTS slots to improve the links established between the end devices. In our previous work (Gomes et al., 2017), an optimized slot allocation model was developed for DSME mode employed in a star topology-enabled WSN. The algorithm was developed for two scenarios. In the first scenario, the request sent by the end device is processed by the algorithm, and depending on the priority of the device, the slot allocation process is completed. In the second scenario, the request sent by the end device is processed by the algorithm, and depending on the range estimation of the device, the slot allocation process is completed.

4 DSME Overview

Consider a WSN that utilizes an IEEE 802.1.5.4e standard for channel allocation and data transmission among the nodes. Intuitively, the standard operates in DSME mode for channel allocation and data transmission. Figure 2 illustrates the network employed for channel allocation and data transmission in DSME mode of operation. Here, the number of sensor nodes (green), coordinators (yellow colour) and PAN coordinator (red colour) are considered for network formation in WSN. Nodes are the end devices employed in the network that transmit the data to the coordinator and PAN nodes. The coordinator nodes are responsible for establishing a connection from one set of nodes to another with the help of the main PAN coordinator node. The PAN coordinator node is responsible for establishing a stable connection among the coordinator nodes and end devices. Initially, the communication between the nodes has to be established with proper synchronization maintained by the PAN coordinator node. Moreover, the PAN coordinator initiates the communication with end devices thereby sending enhanced beacons (EBs) during the beacon interval (BI) in the WSN. The coordinator nodes are employed as relay nodes and help to maintain appropriate communication between the PAN coordinator and end devices.

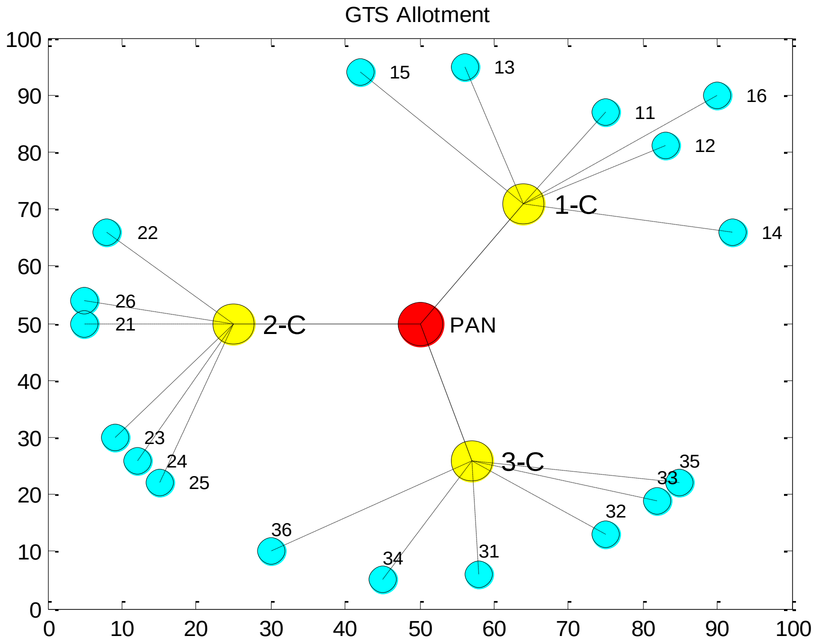


Figure 2: Wireless Sensor Network Employed with IEEE 802.15.4e Standard Operating in DSME Mode

DSME mode of operation incorporates a specific structure for channel allocation and data transmission in WSN. Figure 3 illustrates the DSME structure that contains two superframes in one multi-superframe structure. Furthermore, each superframe operates in three phases: EB's, CAP, and CFP. Initially, at the start of communication, a small-time interval is reserved for sending the EB's to the end devices for setting a proper channel access mechanism in WSN. Next, the PAN coordinator sends the enhanced beacons (EBs) in the WSN. Furthermore, the end devices communicate with each other during the CAP phase with the adoption of a proper channel access mechanism. Lastly, in CFP phase the end devices communicate among themselves with the incorporation of channel adaptation for enabling multichannel for data communication.

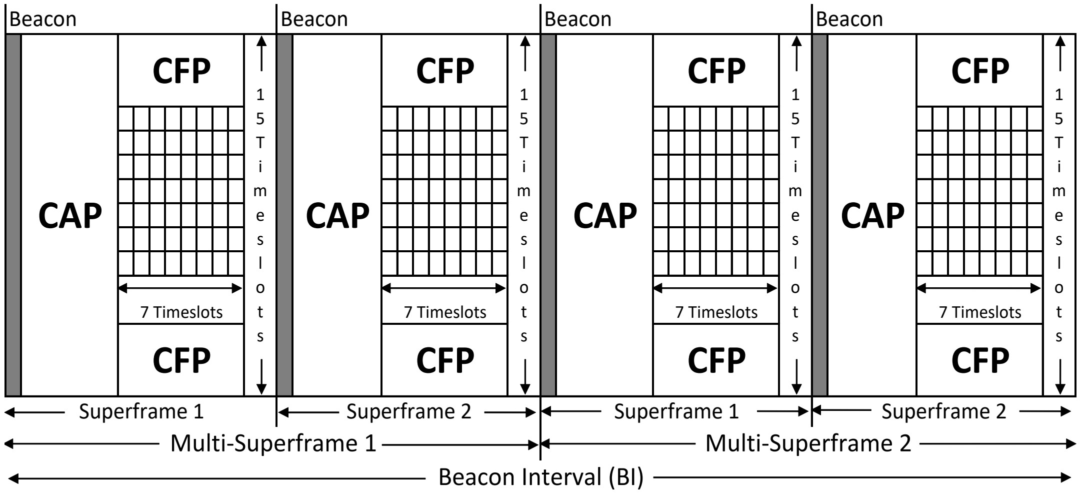


Figure 3: DSME Structure with Beacon Signal, Superframe, and Multi-superframe

In DSME structure, the MO states the multi-frame order, BO states the beacon order, and SO states the superframe order. Furthermore, the multi-frame duration, superframe duration, and beacon interval (BI) are computed by the following expressions and the equation (2) as follows:

$$MD = Duration\ of\ superframe \times 2^{MO}\ symbols, \text{ for } 0 \leq SO \leq BO \leq 14 \tag{2}$$

Next, the expression for BI is defined and the equation (3) as follows:

$$BI = Duration\ of\ superframe \times 2^{BO}\ symbols, \text{ for } 0 \leq BO \leq 14 \tag{3}$$

Finally, the expression for SD is defined and the equation (4) as follows:

$$SD = Duration\ of\ superframe \times 2^{SO}\ symbols, \text{ for } 0 \leq SO \leq BO \leq 14 \tag{4}$$

5 Proposed Methodology

In this section, an optimized DSME-GTS allocation algorithm is developed for WSN depending on the requirements such as bandwidth, delay, throughput, and network traffic. In addition, the slot allocation process is carried out with DSME mode of opera.

tion in IEEE 802.15.4e standard. Figure 4 presents the flowchart for the optimized DSME-GTS allocation algorithm in IEEE 802.15.4e-based networks.

Algorithm starts with the initialization of end nodes, coordinator nodes, and PAN coordinator nodes in WSN. The algorithm is described based on the three phases:

Request Phase

In the first phase, the end devices initiate a request command to the PAN coordinator node with the help of coordinator nodes. In particular, the end devices send this signal based on the number of channels needed for data transmission. After a certain time interval, the end devices wait for the acknowledgement signal from the PAN coordinator node. Depending on the network scenario such as delay, bandwidth, throughput, and traffic specifications the PAN coordinator node performs channel assessment and allocates the multichannel for communication with end devices.

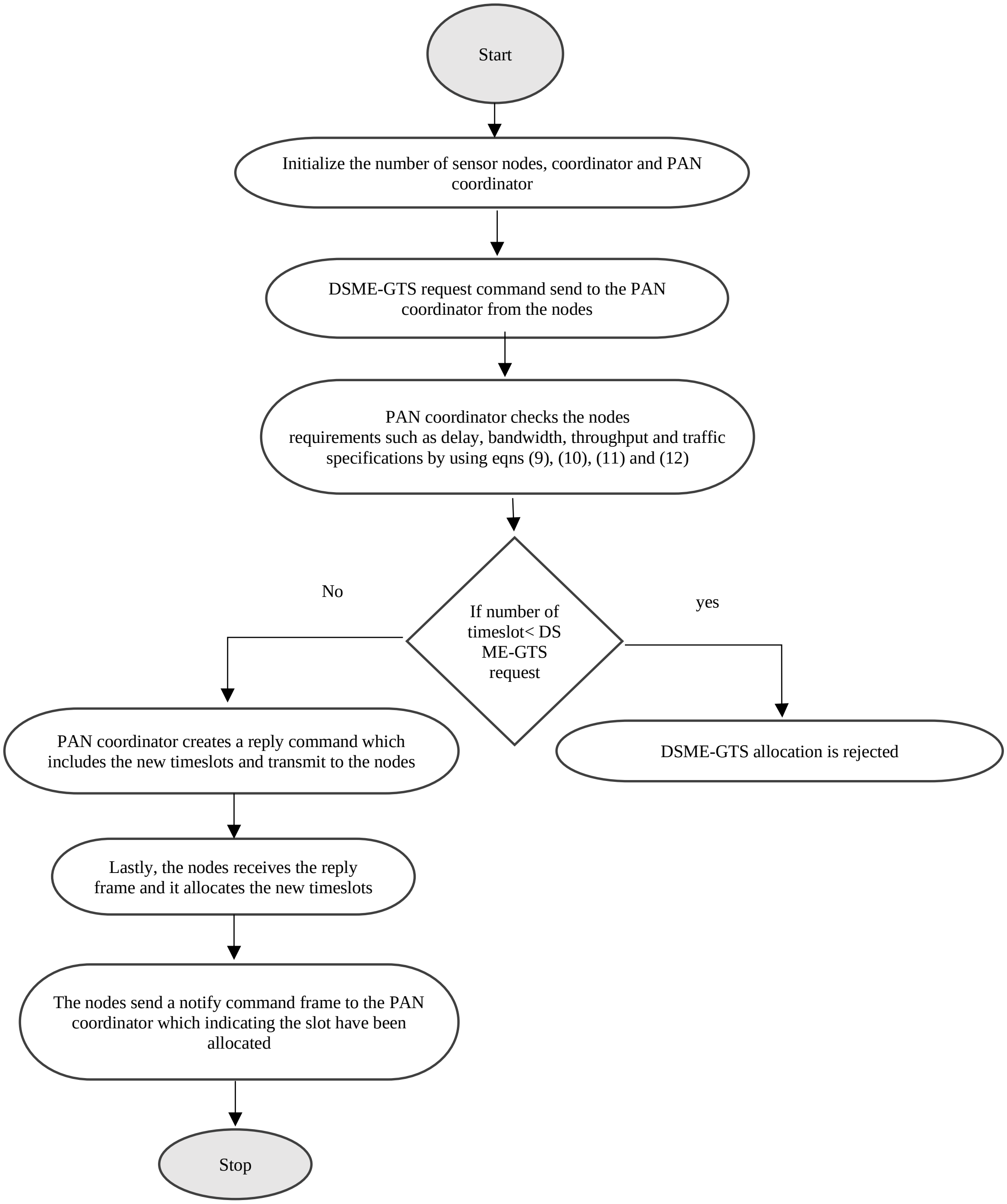


Figure 4: Flow Chart of Optimized DSME-GTS Allocation Algorithm

Reply Phase

In the second phase, based on the request sent by the end devices, the PAN coordinator makes sure that sufficient DSME-GTS slots are available for channel access. If the available slots are less than the requested slots, then the PAN coordinator rejects the signal to the end devices. Next, if the available slots are more than the requested slots, then the PAN coordinator allocates the DSME-GTS slots for the end devices. Lastly, the reply frame signal is sent to all the end devices by the PAN coordinator node.

Notification Phase

In the third phase, based on the reply command received from the PAN coordinator node, the end devices will broadcast a notification command to the PAN coordinator node thereby providing the information about the allocated DSME-GTS slots. Finally, the channel allocation is done for the end devices and enables data transmission between the devices.

Allocation Parameters

In this section, four requirements such as bandwidth, delay, throughput, and traffic specifications are expressed for the algorithm developed for optimization of DSME–GTS slots.

Bandwidth

Bandwidth enables a proper utilization of the DSME structure for data transmission between the end devices. In WSN, bandwidth allocation is a major requirement for end devices for efficient communication. Furthermore, based on the slot's availability, the PAN coordinator node computes the bandwidth requirement which is expressed by equation (5) as follows:

$$\mathrm{B.W} = t_{\mathrm{CAP}} + n \times \frac{t_{\mathrm{mTS}} \leq \mathrm{SD} \times 4 - D_{\mathrm{minCAP}}}{\mathrm{R}} \quad (5)$$

Where, the minimum CAP length is denoted by DminCAP, duration of one mTS is defined by tmTS and R is bit rate in bits per seconds.

Delay

The service request made by the end devices depends on the available slots in the network. Basically, the delay estimation is performed based on the time slots, minimum duration, slot duration, and length of the message. Delay estimation is expressed and the equation (6) as follows:

$$\mathrm{Bd}_{\mathrm{g}} = t_{\mathrm{CAP}} + n \times \left\lceil \frac{\mathrm{B} + D_{\mathrm{IFS}}}{D_{\mathrm{TS}}} \right\rceil \times t_{\mathrm{TS}} \quad (6)$$

Where, the length of time slot is denoted by DTS, CAP minimal duration is defined by tCAP, the length of a message is represented by B and n is less than or equal to 7. The timeslot duration is denoted by tTS, and the length of IFS is described by DIFS.

Throughput

Throughput computation is based on the error-free data transmission among the end devices. Furthermore, the throughput ensures the proper allocation of time slots to enable data transmission among the end devices. Throughput is expressed and the equation (7) as follows:

$$\mathrm{Th} = \frac{R_s L_{pl}}{2\mathrm{N}\,\mathrm{BI}} \sum_{i=1}^{N} r_i\,(\mathrm{M}) \quad (7)$$

Where, N represents the number of devices in WSN, Rs denotes the symbol rate utilized for data transmission, Lpl represents the payload size of the MAC layer, BI represents the beacon interval under the DSME structure, and ri(M) represents the data transmission among the end devices after successful allocation of time slots for ith device in WSN.

Traffic Specifications

In WSN, the traffic specifications depend on network size, allocation of priorities for time slots, the link quality between the nodes, and the range of nodes.

Traffic specification is expressed and the equation (8) as follows:

$$\mathrm{T} = \mathrm{N} \times \mathrm{n} \times \mathrm{t}_{\mathrm{mTS}} < \mathrm{t}_{\mathrm{CAP}} \quad (8)$$

Where, N represents the number of devices in WSN, CAP minimal duration is defined by tCAP, duration of one mTS is defined by tmTS, n is less than or equal to 7.

6 Performance Parameters

The algorithm is analyzed with performance parameters associated with the WSN. In particular, the parameters analyzed are energy consumption, packet delivery ratio, packet loss ratio, and end-to-end delay of the network.

Energy Consumption

During CFP, the end devices communicate with other nodes i.e., enabling the error-free data transmission in WSN. Moreover, the energy consumption is estimated based on the data transmitted and data received by the end devices. Energy consumption is expressed and the equation (9) as follows:

$$E_{GTS} = E_{\boldsymbol{tr}} + E_{\boldsymbol{rcd}} \quad (9)$$

E_{tr} states the energy consumed during data packets transmission. It is stated and the equation (10) as follows:

$$E_{\boldsymbol{tr}} = P_{tr} \sum_{i=0}^{N} (E_{ti}) \quad (10)$$

E_{rcd} states the energy consumed during data packets received. It is stated and the equation (11) as follows:

$$E_{\boldsymbol{rcd}} = P_{rcd} \sum_{i=0}^{N} (E_{ri}), \quad (11)$$

Finally, the overall expression for energy consumption is obtained and the equation (12) as follows:

$$E_{GTS} = P_{tr} \sum_{i=0}^{N} (E_{ti}) + P_{rcd} \sum_{i=0}^{N} (E_{ri}) \quad (12)$$

Where, P_{tr} and P_{rcd} are the power transmitted and power received by end devices respectively.

Packet Delivery Ratio

DSME-time slots are allocated for the end devices to enable the error-free data transmission in WSN. Also, the data received by the end devices needs to be estimated for the performance of WSN. Furthermore, the performance of the network is based on packet delivery ratio (PDR), it is expressed and the equation (13) as follows:

$$PDR_{GTS} = \frac{\sum_{i=0}^{N} P_{Ri}}{\sum_{i=0}^{N} P_{Gi}}, \quad (13)$$

Where, P_{Ri} and P_{Gi} are the data packets received and packets generated by end devices respectively.

Packet Loss Ratio

The number of data packets transmitted by the end devices depends on the available DSME-time slots in the network. The packets transmitted may not reach the other end devices due to link failure or unavailable DSME-time slots. Packet loss ratio (PLR) measures the number of data packets lost in the network to the number of packets generated by the end devices. It is expressed and the equation (14) as follows:

$$PLR_{GTS} = 1 - \frac{\sum_{i=0}^{N} P_{Ri}}{\sum_{i=0}^{N} P_{Gi}}, \quad (14)$$

Where, P_{Ri} and P_{Gi} are the data packets received and packets generated by end devices respectively.

End to End Delay

In WSN, based on requests made by the end devices, and the network size, the data transmitted by end devices may not reach in time to other devices. Hence, a delay is introduced in the network. Delay is estimated based on the difference in time of arrival and generation of data. It is expressed and the equation (15) as follows:

$$E_{D\_GTS} = \sum_{i=0}^{N} (t_{pri}) - \sum_{i=0}^{N} (t_{pti}) \quad (15)$$

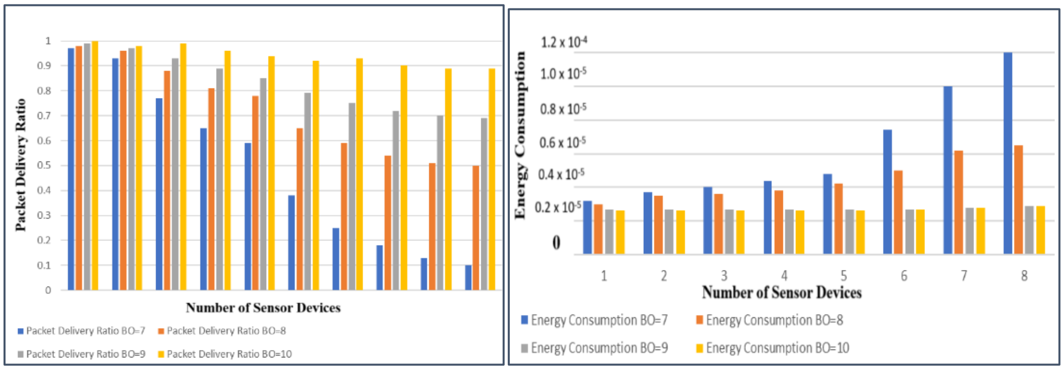
Where, t_{pti} and t_{pri} represents the time at which packets are generated and time at which packets are arrived respectively.

7 Performance Evaluation

In this section, the proposed model is analyzed and simulated using MATLAB 2023a programming tool. Next, a WSN is designed for an area 40 x 40 m^2 with 100 to 1000 nodes employed in the network. Moreover, the nodes in the network operate with a frequency of 2.4 GHz for data communication. Also, the nodes communicate with a data rate of 250 kbps. Group acknowledgement and reduction of CAP are enabled for proper time slot utilization. Table 1 displays the various parameters considered for simulation.

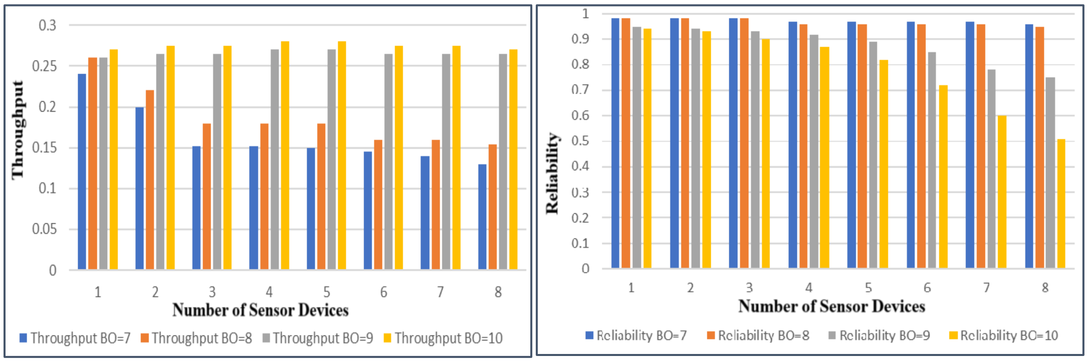
Table 1: Parameters Considered for Simulation

Parameters	Value
Size of the network considered	40 x 40 m^2
Nodes employed in the network	100-1000
Beacon order (BO)	5
Multi-superframe order (MO)	4
Superframe order (SO)	3
Frequency utilized for data communication	2.4 GHz
Rate utilized for data communication	250 kbps
Group Ack	enabled
Reduction utilization for CAP	enabled
Duration utilized for communication	3.84 ms



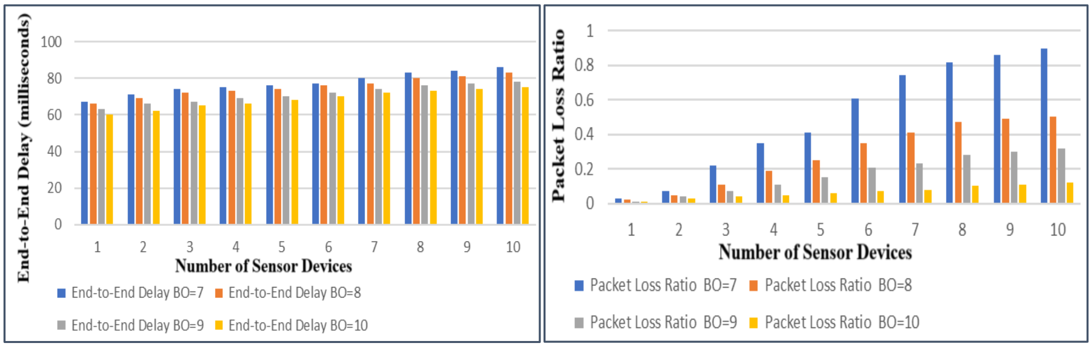
(a) (b)

Figure 5: (a) Packet Delivery Ratio Variation in Beacon Order (BO=7, BO=8, BO=9, BO=10) (b) Energy consumption variation in beacon order (BO=7, BO=8, BO=9, BO=10)



(a) (b)

Figure 6: (a) Throughput Estimation for Variation in Beacon Order (BO=7, BO=8, BO=9, BO=10) (b) Reliability Estimation for Variation in Beacon Order (BO=7, BO=8, BO=9, BO=10)



(a) (b)

Figure 7: (a) End to End Delay Estimation for Variation in Beacon Order (BO=7, BO=8, BO=9, BO=10) (b) Packet Loss Ratio Variation in Beacon Order (BO=7, BO=8, BO=9, BO=10)

Figure 5(a) depicts the estimation of packet delivery ratio (PDR) for the variation in beacon order. It is noticed that PDR is dependent on beacon order. In particular, PDR reduces as the network size is increased. At N=100, PDR achieves higher values (1) for BO=10, later PDR reduces to 0.97 for BO=7. Similarly, at N=1000, PDR achieves higher values (0.89) for BO=10, later PDR reduces to 0.1 for BO=7. Beacon order should be at higher values to achieve better PDR in the network.

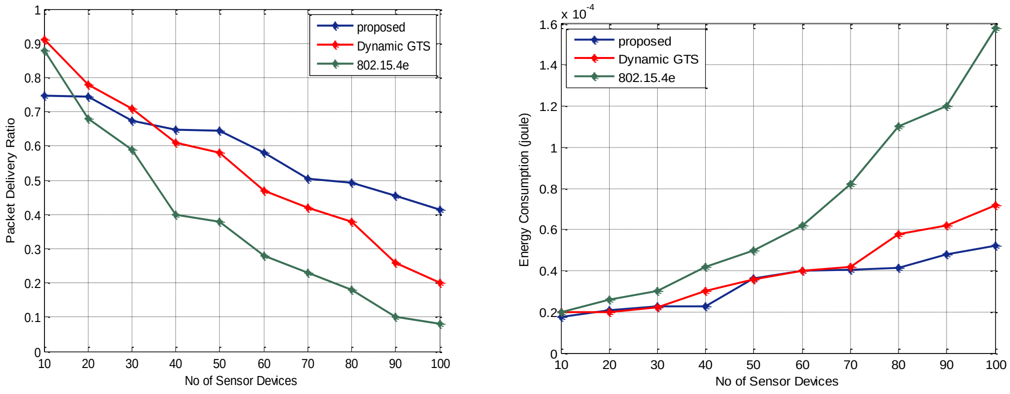
Figure 5(b) depicts the estimation of energy consumption for the variation in beacon order. It is noticed that energy consumption is dependent on beacon order. In particular, energy consumption is high as the network size is increased. At N=100, it achieves a lower value (0.26×10^{-5} joules) for BO=10, later it is increased to 0.32×10^{-5} joules for BO=7. Similarly, at N=750, energy consumption achieves a lower value (0.29×10^{-5} joules) for BO=10, later it is increased to 1.2×10^{-4} joules for BO=7. Beacon order should be at higher values to achieve less energy consumption in the network.

Figure 6(a) depicts the estimation of throughput for the variation in beacon order. It is noticed that throughput is dependent on beacon order. In particular, throughput degrades as the network size is increased. At N=100, throughput achieves higher values (0.27) for BO=10, later throughput reduces to 0.24 for BO=7. Similarly, at N=800, throughput achieves higher values (0.27) for BO=10, later throughput reduces to 0.13 for BO=7. Beacon order should be at higher values to achieve better throughput in the network.

Figure 6(b) depicts the estimation of reliability for the variation in beacon order. It is noticed that reliability is dependent on beacon order. In particular, reliability degrades as the network size is increased. At N=100, reliability achieves lower values (0.94) for BO=10, and later reliability enhances to 0.98 for BO=7. Similarly, at N=800, reliability achieves lower values (0.51) for BO=10, and later reliability enhances to 0.96 for BO=7. The reliability of the network is enhanced for the lower values of beacon order.

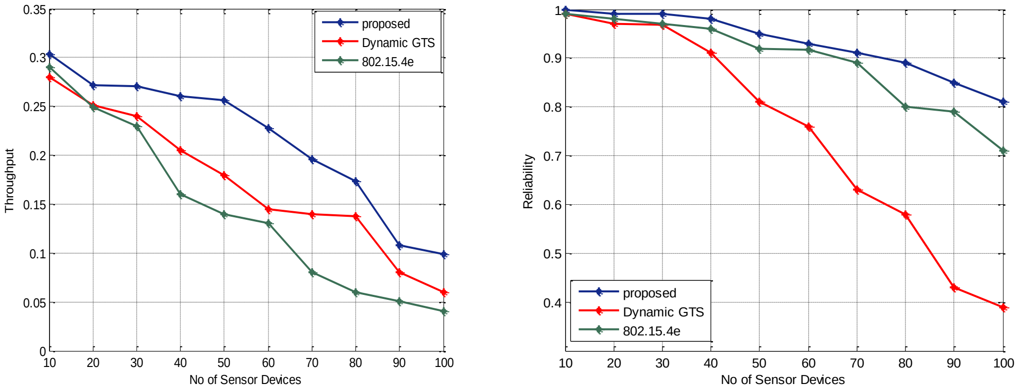
Figure 7(a) depicts the estimation of end-to-end delay for the variation in beacon order. It is noticed that end-to-end delay is dependent on beacon order. At N=100, it achieves a lower value (60ms) for BO=10, later it is increased to 67ms for BO=7. Similarly, at N=1000, it achieves a lower value (75ms) for BO=10, later it is increased to 86ms for BO=7. Beacon order should be at higher values to reduce end-to-end delay in the network.

Figure 7(b) depicts the estimation of packet loss ratio (PLR) for the variation in beacon order. It is noticed that PLR is dependent on beacon order. At N=100, PLR achieves lower values (0.01) for BO=10, later PLR increases to 0.03 for BO=7. Similarly, at N=1000, PLR achieves lower values (0.12) for BO=10, and later PLR increases to 0.9 for BO=7. Beacon order should be at lower values to reduce the PLR in the network.



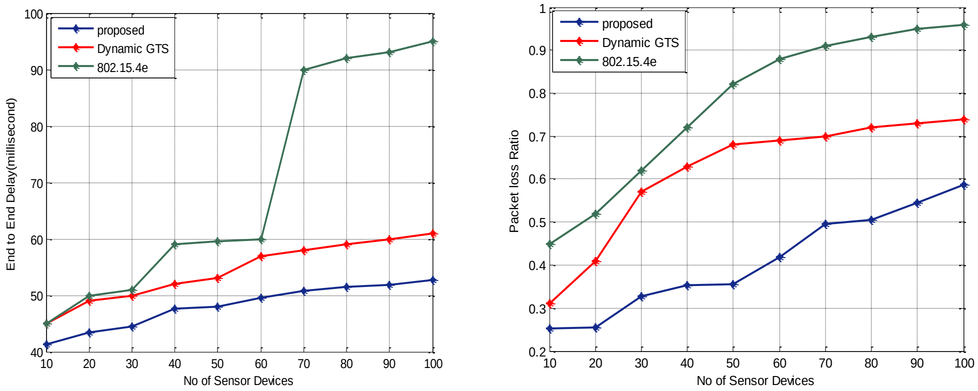
(a) (b)

Figure 8: (a) Packet Delivery Ratio Variation with Network Size Estimated for the Proposed Model and Other Methods (b)Energy Consumption Variation with Network Size Estimated for the Proposed Model and Other Methods



(a) (b)

Figure 9: (a) Throughput Variation with Network Size Estimated for the Proposed Model and Other Methods (b) Reliability Variation with Network Size Estimated for the Proposed Model and Other Methods



(a) (b)

Figure 10: (a) End-to-End Delay Variation with Network Size Estimated for the Proposed Model and other Methods (b) Packet Loss Ratio Variation with Network Size Estimated for the Proposed Model and Other Methods

Figure 8(a) depicts the estimation of packet delivery ratio (PDR) for the variation in network size. Initially, the PDR obtained is very low for a smaller number of devices. Later, as the number of end devices are increased in the network, the proposed model exhibits superior quality to enable multi-channel data communication in the network. Initially, PDR achieves lower values (0.75 to 0.68) for the end devices until N=30, later PDR achieves better values (0.5 to 0.4) for the end devices more than N=50. Also, from analyses, the proposed model exhibits superior quality compared to other models.

Figure 8(b) depicts the estimation of energy consumption for the variation in network size. Initially, the energy consumption obtained is very low for a smaller number of devices. At N=10, energy consumption of the proposed model is 0.19×10^{-4}joules. Similarly, at N=10, the energy consumption estimated by other methods is 0.2×10^{-4}joules. At N=100, the energy consumption of the proposed model is 0.52×10^{-4}joules. Similarly, at N=100, the energy consumption estimated by other methods are 0.72×10^{-4}joules and 1.6×10^{-4}joules. Initially, less difference is observed in energy consumption. Later, as the network size is increased, the proposed model exhibits better performance when compared to other methods.

Figure 9(a) depicts the estimation of throughput for the variation in network size. Initially, the throughput obtained is very high for a smaller number of devices. Later, as the number of end devices are increased in the network, throughput reduces due to loss in data packets in the network. At N=10, the throughput of the proposed model is 0.3. Similarly, at N=10, the throughput estimated by other methods are 0.28 and 0.27. At N=100, the throughput of the proposed model is 0.1. Similarly, at N=100, throughput estimated by other methods are 0.06 and 0.04.

Figure 9(b) depicts the estimation of reliability for the variation in network size. Initially, reliability is very high for a smaller number of devices. Later, as the number of end devices are increased in the network, reliability is degraded due to loss in data packets in the network. At N=10, the reliability of the proposed model is 0.99. Similarly, at N=10, the reliability estimated by other methods are 0.98 and 0.97. At N=100, the reliability of the proposed model is 0.82. Similarly, at N=100, reliability estimated by other methods are 0.72 and 0.38.

Figure 10(a) depicts the estimation of end-to-end delay for the variation in network size. At N=10, the end-to-end delay of the proposed model is 42ms. Similarly, at N=10, the end-to-end delay estimated by other methods is 45ms. At N=100, the end-to-end delay of the proposed model is 54ms. Similarly, at N=100, the end-to-end delay estimated by other methods are 61ms and 95ms. The model developed exhibits superior performance when compared to other models.

Figure 10(b) depicts the estimation of packet loss ratio (PLR) for the variation in network size. At N=10, the PLR of the proposed model is 0.25. Similarly, at N=10, the PLR estimated by other methods are 0.31 and 0.45. At N=100, the PLR of the proposed model is 0.58. Similarly, at N=100, the PLR estimated by other methods are 0.74 and 0.96.

8 Comparative Analysis

Table 2 presents the comparative analysis of the proposed Model, Dynamic GTS, and the standrad DSME.

Table 2: Comparative Analysis of the Proposed Model, Dynamic GTS, and the Standard DSME

Parameter	**DSME-Approaches**	**Nodes employed in the network**		
		At (N=10)	**At (N=50)**	**At (N=100)**
Packet delivery ratio variation with network size	Proposed Model	0.75	0.65	0.65
	Dynamic GTS	0.91	0.58	0.201
	Standard DSME	0.88	0.38	0.08
Energy consumption variation with network size	Proposed Model	0.19×10^{-4} joules	0.38×10^{-4} joules	0.52×10^{-4}joules
	Dynamic GTS	0.2×10^{-4} joules	0.38×10^{-4} joules	0.72×10^{-4}joules
	Standard DSME	0.2×10^{-4} joules	0.5×10^{-4} joules	1.6×10^{-4}joules
Throughput variation with network size	Proposed Model	0.3	0.26	0.1
	Dynamic GTS	0.28	0.18	0.06
	Standard DSME	0.29	0.14	0.04
Reliability variation with network size	Proposed Model	0.99	0.95	0.82
	Dynamic GTS	0.98	0.92	0.72
	Standard DSME	0.97	0.81	0.38
End-to-End delay variation with network size	Proposed Model	42ms	48ms	54ms
	Dynamic GTS	45ms	54ms	61ms
	Standard DSME	45ms	60ms	95ms
Packet loss ratio variation with network size	Proposed Model	0.25	0.35	0.58
	Dynamic GTS	0.31	0.68	0.74
	Standard DSME	0.45	0.82	0.96

9 Conclusion

In this paper, an optimized DSME-GTS allocation algorithm is developed for IEEE 802.15.4e-based networks depending on the requirements such as bandwidth, delay, throughput, and network traffic. The algorithm assigns the DSME-GTS slots to all the end nodes by the PAN coordinator at the end of the notification phase. In general, the proposed algorithm allocates the DSME-GTS slots in three phases. In first phase, the PAN coordinator node allocates the multichannel to enable communication with end devices. In second phase, the PAN coordinator sends a reply signal to end devices. In third phase, the end devices will broadcast a notification command to the PAN coordinator node thereby providing the information about the allocated DSME-GTS slots. In addition, the performance parameters such as packet delivery ratio, packet loss ratio, throughput, reliability, energy consumption, and end-to-end delay of the network are analyzed. Finally, the algorithm is simulated using MATLAB 2023a programming tool and comparative analysis is carried out with other schemes.

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