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Performance Analysis of Modified IEEE 802.15.4e MAC for Wireless Sensor Networks

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ABSTRACT

Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) is the most popular channel access mechanism for Wireless Sensor Networks (WSNs). The random backoff and CCAs in CSMA/CA mechanism avoid the collisions. However, inefficient CCAs increase energy consumption. In order to reduce the energy consumption and enhance the reliability, a new channel access mechanism for IEEE 802.15.4e is proposed here. Besides, performance of the proposed MAC is analyzed in terms of reliability and throughput. Our models are compared with IEEE 802.15.4e MAC. It is found that the performance of the proposed MAC can outperform in terms of throughput, reliability, energy, transmission and channel access failure rate.

CCS CONCEPTS

• **Computer systems organization**; • **Computer Communication Networks**; • **Mathematics of Computing**; • **Computing Methodologies**; • **Simulation and Modeling**;

KEYWORDS

Wireless Sensor Networks, IEEE 802.15.4e, modeling.

1 INTRODUCTION

Wireless Sensor Network (WSN) is typically composed of tiny, inexpensive battery-powered wireless devices with limited computing and communication capabilities. Internet of Things (IoT) holds enormous promise of new capabilities for users and new opportunities for different applications, where low latency, low energy consumption and high data reliability are the critical requirements. WSN is the indispensable part of the IoT and acts as the bridge that connects the real world to the digital one with responsibility for passing on the sensed data to the base station with minimum delay. Wireless sensor networks (WSNs) comprise different types of battery-operated sensor devices like low sampling rate, thermal, visual, infrared, seismic, radar, magnetic and acoustic, which are deployed to collect, process, and transfer data. The WSNs are initially developed for monitoring militant activities in harsh environment and protecting the force. However, it can be used in many industrial and consumer applications to monitor and control the industrial process, machine health, air pollution and many others. Energy is the major constraints for these battery-operated sensor devices in WSN and network lifetime of a WSN is always limited by sensor devices' energy. Hence, maintaining a long network lifetime is one of the important research issue in WSNs.

IEEE 802.15.4 [1] is a well-known standard for the medium access control (MAC) scheme and is the reference communication technology for WSNs. However, it cannot meet the requirements like low latency for industrial and commercial applications. Hence, IEEE 802.15.4e Working Group has redesigned the existing IEEE 802.15.4 MAC scheme. Different MAC schemes such as Low Latency Deterministic Networks (LLDN), Radio Frequency Identification blink (RFID), Time Slotted Channel Hopping (TSCH), Asynchronous Multi-Channel Adaptation (AMCA), Deterministic and Synchronous Multi channel Extension (DSME) are suggested for different applications defined by IEEE 802.15.4e. However, IEEE 802.15.4e [2] standard upholds the same slotted/unslotted medium access control scheme of IEEE 802.15.4 for the short-range communication devices with low data rates.

IEEE 802.15.4e medium access control (MAC) scheme performs slotted carrier sense multiple access with collision avoidance to access the channel and uses a random backoff algorithm to reduce the collision probability. The main goal of CSMA/CA is to coordinate the contending devices to access the channel in a distributed way. To save energy, devices go to power saving mode during backoff duration and perform carrier sensing after the backoff duration is over. The channel gets busy either due to data or acknowledgment transmission. However, the existing scheme in IEEE 802.15.4e cannot differentiate the cause of busy channel either due to data or acknowledgment. Moreover, when the tagged device finds the channel busy during the carrier sensing, it doubles the contention window size and goes for a random backoff with CCA, which degrades the network performance with respect to energy consumption, throughput and reliability. Besides, the probability of choosing the same backoff value due to limited backoff window size is high and the collision rate increases with respect to the increasing number of contending devices. After every collision, CSMA/CA executes finite numbers of retransmission operations and then the packet is dropped if fails to retransmit. Hence, it is

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crucial to investigate the current problems and find out solutions to reduce their influence on the performance of the overall network.

In order to mitigate the above discussed problems, the main contributions of our work can be summarized as follows.

- A novel channel access scheme is designed for wireless sensors to enhance the throughput, reduce the power consumption and delay.
- A Markov chain model is designed to analyze the performance of our proposed channel access scheme.
- Performance analysis of our proposed method is made to study the impact of hidden terminal problem on reliability, throughput and energy consumption.

Rest of the paper is organized as follows. Related works are given in Section 2. Network model and proposed methods are presented in Section 3. Analytical models are designed in Section 4 and Performance analysis is given in Section 5. Simulation results are discussed in Section 6 and concluding remarks are made in Section 7.

2 RELATED WORKS

The CSMA/CA mechanism of IEEE 802.15.4e is widely employed in WSNs due to energy efficiency and performance robustness. When a device wishes to transmit data frames, it initializes the variables NB and BE, where NB represents the number of attempts to access the channel before the transmission and BE is the backoff exponent. Before accessing the channel, the device waits for a random number of backoff slots in the range of $[0, 2^{BE-1}]$. In order to save energy, devices are in sleeping state during this random backoff durations. The tagged device starts channel access in the form of two times CCA at the end of backoff duration. The tagged device starts data transmission provided channel is found idle during these two CCAs and waits for the acknowledgment. If a device finds the channel busy during the CCAs, it increases the value of BE and NB by one and goes for the random backoff again. The maximum value of BE, NB are BE_{max} and maxMacBackoff (NB_{max}), respectively. The device drops the packet when the value of NB exceeds NB_{max}.

In the literature, several works have studied the performance analysis of IEEE 802.15.4 networks. Some studies have tried to design and analyze the behavior of IEEE 802.15.4 MAC protocol. However, none of them focuses on the exact nature of the IEEE 802.15.4e MAC as expressed in this paper. Collision and interferences are two common reasons for degradation of the network performance in WSNs. The major power consumption of battery enabled ZigBee device is due to data retransmission when there is a collision or interferences. The slotted CSMA/CA mechanism of IEEE 802.15.4e [2] adopts binary exponential backoff scheme to reduce collision probability. However, to save power consumptions in WSNs, the slotted CSMA/CA mechanism follows the blind random backoff without considering the real cause of the busy channel and causes longer delay. The tagged device can start transmission after the acknowledged packet when it can get accurate information that the busy channel is caused by data or an acknowledged packet during CCA. Hence, to avoid further delay authors in [3] have designed one additional carrier sensing (ACS) algorithm through the information during the second CCA. However, this method increases the energy consumptions for the battery enabled Zigbee devices with this additional CCA. In order to avoid further energy consumptions due to this additional CCA, authors in [4] have proposed one new MAC protocol that can avoid the channel busy due to acknowledgment packet transmission without any additional CCA. However, authors have not considered the hidden terminal problem and the proposed two idle slots between first and second CCA enhance little delay in sparse network without hidden terminal problem.

In IEEE 802.15.4e one backoff slot is about 20 symbols. However, one acknowledgment packet is about 22 symbols. CSMA/CA performs two successive CCAs to determine the channel status and go for random backoff if the channel found as busy during CCA. Hence to increase the chance of transmission through avoiding the channel busy condition due to ACK packet, authors in [5] proposed one segmentized CCA method, where CCA duration is divided in to two group and their energy level are compared to get the channel status during CCA. The proposed CCA method can assess the channel idle at the end of the ACK packet. However, it cannot restrict one device for accessing channel, when any other device waiting for the acknowledged packet after finishing data transmission, and found channel busy during second CCA due to ACK one. In order to overcomes the short comings of the IEEE 802.15.4 standard MAC the authors in [6] suggested to use more than two CCA to increase the chance of transmission with the coexistence of WiFi devices in the network. However, this practices decrease the network lifetime.

Analytical model is designed in [7] to predict the energy consumption and throughput in WSNs for the saturated and unsaturated traffics under ideal channel condition. Similar type of mathematical model for the beacon-enabled mode of IEEE 802.15.4 is suggested in [8]. However, these works not focus how to enhance the reliability of the network. Considering the effects of multi-path shadow fading channels in WSNs, authors in [9] designed one Markov model to analyze the reliability, delay with respect to different traffic rates. In WBAN application with identifying the most critical physiological parameter and the concerned sensor device, an analytical model is proposed in [10] for reliable communication by optimizing the MAC-frame payload. However, it cannot avoid channel busy during CCA due to ACK one that forces the tagged device to go for another random backoff period and ultimately increase delay.

Analytical model is designed in [11] to evaluate the battery lifetime in IEEE 802.15.4 based on metering network considering the impact of hidden terminal problem. However, authors not considered how to enhance the real time reliable transmission. In order to handle the event driven data, where a sequence of transmission subsequently occurs, authors in [12] design one model to analyze the most likely events and parallel computation. In this paper, we propose a new channel access mechanism in WSNs to reduce the power consumption and delay. In addition, one analytical model is proposed to evaluate the performance in terms of reliability and throughput considering the hidden terminal problem.

3 PROPOSED METHODS

Consider a wireless network, where N numbers of devices are contending to transmit data frames to a common receiver. Topology of the network can be both star or mutihop. In case of a star network, the devices start transmitting data to the coordinator devices and in

Table 1: Notation table

Notation	Meaning
N	Total number of nodes in a system.
NB	Number of attempts to access the channel.
BE	Backoff exponent.
RT	Number of retransmission attempts.
T_D	Length of a data packet.
L_{ACK}	Length of an acknowledgment.
CCA	clear channel assessment
λ	Packet arrival rate.
R_b	Random backoff.
ϕ	channel sensing probability.
α_1	CCA_1 busy probability due to data packet.
α_2	CCA_1 busy probability due to ACK packet.
β_1	CCA_2 busy probability due to data packet.
β_2	CCA_2 busy probability due to ACK packet.
P_e	Probability of channel error.

case of multihop mesh network, the devices transmit the data to a common parent/neighbor device. It is assumed that the transmission range of the devices is equal to their sensing range. We assume that p_h percentage of hidden devices with respect to each device is present within the network. The CSMA/CA mechanism allows the devices to access the channel uniformly. In our proposed model, all devices follow CSMA/CA mechanism during the contention access period to transmit the data frames. Since, power consumption is one of the major issues in WSNs, all devices go for the power saving mode after data transmission. Collisions between devices may occur in case of two or more devices perform channel sensing at the same time or during ongoing transmission due to hidden terminal problem, and transmit their packets upon finding the channel idle. Notations of different parameters are given in Table 1.

3.1 Estimation of received power

In this section, we discuss how our mechanism can detect acknowledgment packet through received power. All the devices those present in the one hop neighbor received the beacon packet from the coordinator and devices calculate the beacon received power level P_{br} as follows.

$$P_{br} = P_{max}(\frac{\lambda}{4\Pi d})^n g_t g_r \tag{1}$$

where
λ wavelength;
d distance between the sender and receiver antenna;
n path loss coefficient;
g_t antenna gain at sender;
g_r antenna gain at receiver.

With this estimation we are in view that the devices can differentiate the data packet and acknowledgment and detect the acknowledgment packet more accurately based on the energy detection during CCA. The detail method is discussed in the section 3.2

3.2 Proposed channel access mechanism

CSMA/CA scheme is the key component in IEEE 802.15.4e MAC and all devices have equal probabilities for accessing the channel. However, when too many devices have data and they try to access the channel simultaneously increases the collision and makes the channel busy. In order to save power consumption, the devices use power saving mode during the backoff duration and perform carrier sensing after the backoff duration is over. The channel access scheme suggested by IEEE 802.15.4e standard simply adopts a random backoff with clear channel assessment (CCA). The tagged device after finding the channel idle in the first CCA performs the second CCA and the transmission is started if the channel is found idle during second CCA. This procedure is repeated if the channel is found busy during any CCA, which may be incurred by four reasons.

- **Case 1:** When a tagged device performs the first CCA during on going transmission of data packet by any other device in the network.
- **Case 2:** When a tagged device performs the first CCA during the exchange of acknowledgment by other devices.
- **Case 3:** When a tagged device performs the first CCA and in that slot another device performs its second CCA and starts transmission during its second CCA.
- **Case 4:** When a tagged device performs the first CCA during the acknowledgment waiting time of another device and finds channel busy during the second CCA due to the exchange of acknowledgment by other devices.

Once the channel is found busy, the tagged device doubles the contention window size and goes for random backoff before accessing the channel again. Let, P_{cca} be the received power during CCA. To avoid the unnecessary backoff duration, and energy consumption due to CCA, we compare the received power during CCA (P_{cca}) with the received power during beaconing (P_{br}) as discussed in Section 3.1 to ignore the channel busy due to case 2 and case 4. The detail procedure of our proposed scheme is described in Algorithm 1.

Algorithm 1 New channel access mechanism.

```
Require: Number of devices $N$, $NB = 0$, $BE = macMinBE$, $RT = 0$.
Ensure: Transmission success or failure.
 1: Listen to the channel;
 2: if (Beacon not received) then
 3:     Wait for beacon;
 4: else
 5:     Random backoff $R_b = random(0, 2^{BE-1})$;
 6: end if
 7: Perform $CCA_1$ after $R_b$ duration;
 8: if (channel busy && $P_{cca} \approx P_{br}$) then
 9:     Wait for one slot and go to step 25;
10: else if (channel busy && $P_{cca} \neq P_{br}$) then
11:     Switch to sleep state for the random$(0, T_D)$ and go to step 19;
12: end if
13: Perform $CCA_2$;
14: if (channel busy && $P_{cca} \approx P_{br}$) then
15:     Wait for one slot and go to step 25;
16: else if (channel busy && $P_{cca} \neq P_{br}$) then
17:     Switch to sleep state for the random $T_D$ and go to step 19;
18: end if
19: $NB = NB + 1$, $BE = minimum(BE + 1, macMaxBE)$;
20: if ($NB > NB_{max}$) then
21:     Stop due to channel access failure;
22: else
23:     go to step 5;
24: end if
25: Start transmission and wait for ACK;
26: if (ACK is not received) then
27:     $RT = RT + 1$;
28:     if ($RT \leq RT_{max}$) then
29:         go to step 5;
30:     else
31:         Stop due to transmission failure;
32:     end if
33: end if
```

Based on our proposed carrier sensing algorithm, devices in the network can ignore completely the channel busy due to acknowledgment and a device may go for the power saving mode for the entire data transmission duration upon finding the channel busy during second CCA. Thus power consumption, delay are reduced significantly by avoiding the unnecessary random backoff with CCAs and simultaneously network lifetime can be increased.

4 MARKOV MODELS OF PROPOSED MAC

Let us assume N number of devices are associated with a coordinator. For a given device, the stochastic processes $s(t)$ and $c(t)$ represent the backoff stage for NB and backoff counter for CW, respectively as shown in Fig. 1. Let,

$$S_{i,j} = \lim_{t\to\infty} P\{s(t) = i, c(t) = j\}$$

where $j \in \{-1, ..., W_i - 1\}$,
$W_i = 2^{min(i+macMINBE, macMAXBE)}$ for $i \in \{0, ..., m\}$. The time t corresponds to the beginning of the slot time and is directly related to the system time. $S_{i,0}$ represents the states corresponding to the channel access for $i \in \{0, ..., m\}$ after the backoff counter reaches to zero. T, R, I_{os} and I represents the transmission, ready, idle and initial states respectively. The device will be in transmission state after found the channel idle during it's CCAs. But the device will remain in initial state when it has no request packet to transmit. Let, p_1 is defined as the probability that the device has packet to transmit. After generating the packet the device moves to the ready state R. Reaching at ready state the device performs random backoff and proceeds to the state $S_{0,k}$, where $k \in \{0, 1, 2..., W_0 - 1\}$ accordingly. The state $S_{i,j}$ represents the backoff states, where $i \in \{0, ..., m\}$ and $j \in \{-1, ..., W_i - 1\}$. Let, α_1, α_2 are the probability of accessing channel busy during the first CCA due to data and acknowledgment packet respectively. Let, β_1, β_2 are the probability of accessing channel busy during the second CCA due to data and acknowledgment packet respectively. A device moves to the transmission state, if the channel found to be idle during CCAs and attempts to transmit requests. Let P_s the probability that the transmission is successful. Based on the proposed Markov chain model given in Fig. 1, we get

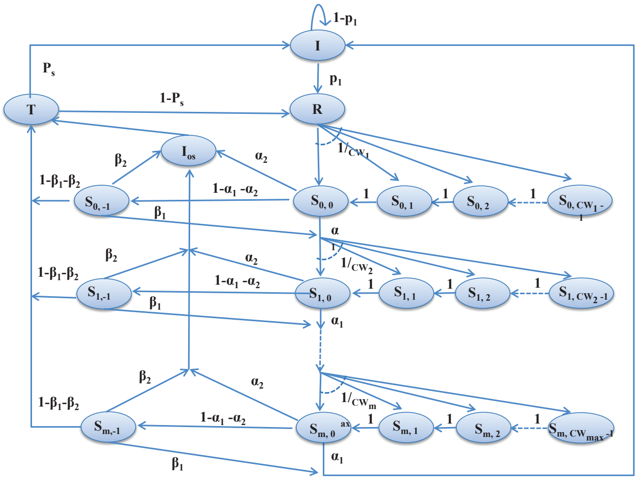

Figure 1: Markov models for the proposed channel access mechanism.

as in figure the transition probabilities used to derive the steady state probabilities are

$$P\{S_{i,k}|S_{i,k+1}\} = 1 \;\; for\ 0 \leq i \leq m\ and\ 0 \leq k \leq W_i - 1. \quad (2)$$

$$P\{S_{i,k}|S_{i-1,0}\} = \frac{\alpha_1 + (1-\alpha_1-\alpha_2)\beta_1}{W_i} \quad for\ 1 \leq i \leq m\ and\ 0 \leq k \leq W_i - 1. \quad (3)$$

$$P\{I|S_{m,0}\} = (\alpha_1 + (1-\alpha_1-\alpha_2)\beta_1) + (\alpha_2 + (1-\alpha_1-\alpha_2)(1-\beta_1))P_S. \quad (4)$$

Equation 2 represents the decrement of backoff counter which happens with probability 1. Equation 3 represents the probability of finding channel busy during CCA and thereafter a device selects uniformly a state in the next backoff stage. Equation 4 gives the probability of going back to the initial state from the last backoff stage after finding channel idle or busy during CCAs. Based on these transition probability we can derive the steady state probabilities as follows

$$S_{i,k} = \frac{W_i - k}{W_i}(S_{i-1,0}(\alpha_1 + (1-\alpha_1-\alpha_2)\beta_1); \\ for\ 1 \le i \le m\ and\ 0 \le k \le W_i - 1. \tag{5}$$

$$S_{0,k} = \frac{R}{W_0}. \tag{6}$$

$$S_{i,-1} = (1-\alpha_1-\alpha_2)S_{i,0} \ \ for\ 0 \le i \le m. \tag{7}$$

$$I_{os} = \alpha_2 S_{i,0} + \beta_2 S_{i,-1} \ \ for\ 0 \le i \le m. \tag{8}$$

$$T = I_{os} + (1-\beta_1-\beta_2)S_{i,-1} \ \ for\ 0 \le i \le m. \tag{9}$$

$$R = (1-p_1)I. \tag{10}$$

$$I = \frac{(\alpha_1 + (1-\alpha_1-\alpha_2)\beta_1)S_{m,0} + P_s T}{p_1}. \tag{11}$$

By the property of the total probability and using the above states, finally we get

$$I + R + \sum_{i=0}^{m}\sum_{j=0}^{W_i-1} S_{i,j} + \sum_{i=1}^{m} S_{i,-1} + I_{os} + T = 1. \tag{12}$$

The probability ϕ that device attempts carrier sensing for first time within a slot for transmitting is

$$\phi = \sum_{i=0}^{m} S_{i,0}. \tag{13}$$

5 PERFORMANCE ANALYSIS

In this section, we analyze the reliability and throughput of IEEE 802.15.4e through our Markov model as discussed in Section 4.

5.1 Reliability

A transmission is always successful when exactly one device transmits without any channel error or collision. Let, p_1 be the probability for a device having packet for the transmission, p_e be the channel error rate, N is the number of devices having data to transmit, p_h percentage of hidden devices with respect to each device. Hence the expected number of hidden devices are Np_h. The device having data to transmit found channel busy during CCAs due to either data or acknowledgment packet. The tagged device found channel busy due to data packet if any other device in its vicinity is transmitting during its CCA. Acknowledgment will be transmitted only if there is a successful transmission and packet transmission is successful, if exactly one device is transmitting data without any collision and channel error.

Let, $\alpha_1,\ \alpha_2$ are the probability of accessing channel busy during the first CCA due to data and acknowledgment packet respectively and $\beta_1,\ \beta_2$ are the probability of accessing channel busy during the second CCA due to data and acknowledgment packet respectively. Considering the length of the data packet as L_D and acknowledgment as L_{ack}, we can derive $\alpha_1,\ \alpha_2, \beta_1,\ \beta_2$ as follows.

$$\alpha_1 = L_D(1-(1-\phi)^{N(1-p_h)-1}) \\ (\alpha_2 + (1-\alpha_1-\alpha_2)(1-\beta_1)) \tag{14}$$

$$\alpha_2 = N(1-p_h)\phi(1-\phi)^{N(1-p_h)-1}(1-p_e) \\ (1-\phi)^{2L_D N p_h}(\alpha_2 + (1-\alpha_1-\alpha_2)(1-\beta_1)) \tag{15}$$

$$\beta_1 = \frac{1-(1-\phi)^{N(1-p_h)-1)}}{2-(1-\phi)^{N(1-p_h)}} \tag{16}$$

$$\beta_2 = (N(1-p_h)-1)\phi(1-\phi)^{N(1-p_h)-2}(1-p_e) \\ (1-\phi)^{2L_D N p_h}(\alpha_2 + (1-\alpha_1-\alpha_2)(1-\beta_1)) \tag{17}$$

The device will go for the next backoff, if the channel access fails. Hence, the probability of going to the next backoff is

$$P_{bf} = \alpha_1 + (1-\alpha_1-\alpha_2)\beta_1 \tag{18}$$

A transmission will be successful, if the device receives the acknowledgment packet corresponding to its transmission. Hence the probability of successful transmission by a device is

$$P_s = N(1-p_h)\phi(1-\phi)^{N(1-p_h)-1}(1-p_e) \\ (1-\phi)^{2L_D N p_h} \tag{19}$$

Considering the upper bound for retransmission as r, we can derive the probability of transmission failure as follows.

$$P_{tf} = (1-p_s)^{r+1} \tag{20}$$

Similarly, if the upper bound of channel access as m, we can derive the probability of channel access failure as follows.

$$P_{cf} = (\alpha_1 + (1-\alpha_1-\alpha_2)\beta_1)^{m+1} \tag{21}$$

Hence, the reliability is

$$P_r = 1 - P_{cf} - P_{tf} \tag{22}$$

5.2 Throughput

The data packet will be successfully transmitted, if the device synchronizes and transmits the data successfully. The throughput is expressed as the fraction of time spent in transmitting the data packet successfully. The maximum throughput can be achieved in the network when exactly one node transmits the data to the destination Hence, the throughput can be derived as follows.

$$T_p = L_D P_s PHY_{rate} \tag{23}$$

where L_D, P_s, PHY_{rate} are the payload, probability of successful packet transmission and the physical data rate of IEEE 802.15.4e.

Table 2: Simulation parameters

Parameters	Value
Radio band	2.4GHz
Channel bandwidth	250kbps
Carrier sense sensitivity	-85 dBm
Channel number	11
Beacon interval	$15.6 \times 2^5 ms$
Unit backoff period	20 symbol
PHY overhead	6 byte
MAC overhead	3 byte
Transmission current consumption	9.1 mA
Receiving current consumption	5.9 mA
Turnaround current consumption	7.5 mA
Sleep current consumption	0.001 mA

6 PERFORMANCE EVALUATION

In this section, we evaluate our model by using OMNeT++ [13] simulator. We conduct the simulation to compare our proposed protocol performance with IEEE 802.15.4e. In this paper we consider devices are randomly located in the area of 50 x 50 m^2. We compare our work with the IEEE 802.15.4e standard for successful transmission, throughput, reliability, transmission failure rate, and channel access failure over Poisson arrival rate. The simulation parameters are set as per the IEEE 802.15.4e standard and are provided in Table 2.

Fig. 2, compares the reliability of data transmission with respect to different nodes. It is observed that the reliability decreases as the arrival rate of nodes attached to a coordinator increases. When the data payload of 100 bytes and fifteen number of nodes are considered, it is observed that the reliability of our work is higher than the IEEE 802.15.4e protocol.

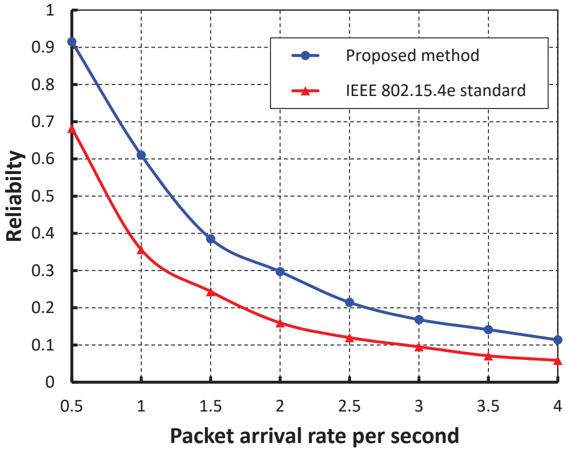

Figure 2: Comparison of reliability of our proposed protocol with the IEEE 802.15.4e standard.

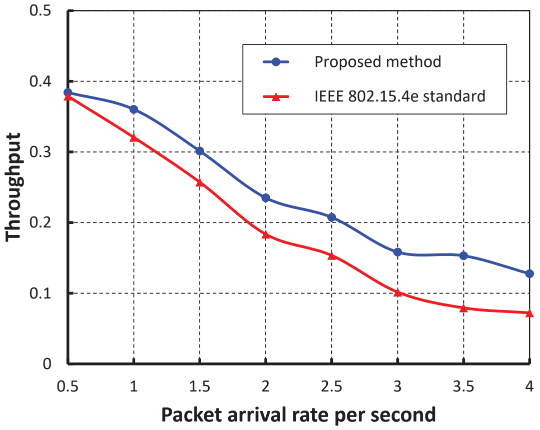

Figure 3: Comparison of throughput of our proposed protocol with the IEEE 802.15.4e standard.

Fig. 3, demonstrates the throughput corresponding to the data arrival rates of nodes. When the data payload is 100 bytes and fifteen devices are attached to the coordinator, We observe that the throughput decreases as the arrival rate of devices attached to a coordinator increases. It is observed that throughput of our work is higher. Fig. 4, shows the energy consumption in joule/byte with different data arrival rates. It is observed that the energy consumption of our work is significantly less than the IEEE 802.15.4e protocol.

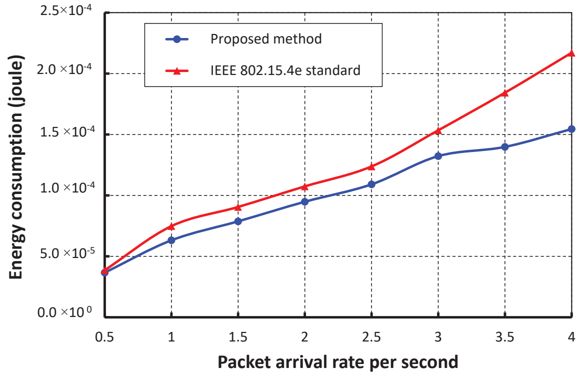

Figure 4: Comparison of energy consumption of our proposed protocol with the IEEE 802.15.4e standard.

As shown in Fig. 5, The Y axis is the transmission failure probability and the X axis is the different data arrival rate. The transmission failure probability increases with respect to the data arrival rate. It is found that the transmission failure probability of our work is significantly less than the IEEE 802.15.4e protocol.

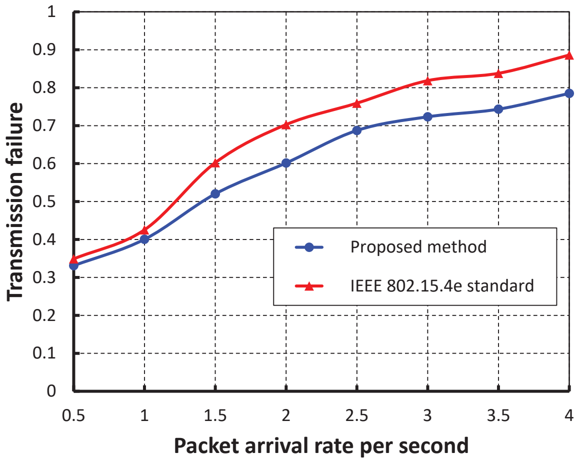

Figure 5: Comparison of transmission failure of our proposed protocol with the IEEE 802.15.4e standard.

Fig. 6, shows the channel access failure rate with variable arrival rate. It is observed that the channel access failure rate increases as the arrival rate increases. When the data payload is 100 bytes and fifteen number of nodes are considered, the channel access failure rate of our work is significantly less than the IEEE 802.15.4e protocol.

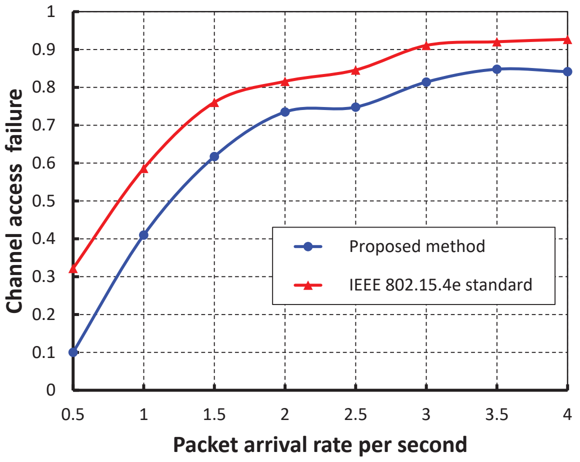

Figure 6: Comparison of channel access failure rate of our proposed protocol with the IEEE 802.15.4e standard.

7 CONCLUSIONS

In this paper, we propose a new channel access mechanism, which can significantly reduce the energy consumption. Analytical models are designed to study the performance metrics of WSNs such as reliability and throughput. The results obtained from the simulation indicate that our protocol can improve the energy, reliability, throughput, channel access failure rate and transmission failure rates significantly. Hence, our protocols can be implemented in WSNs , where energy, reliability and throughput are the major requirements.

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