

# Optimized Performance of IEEE 802.15.4e DSME for Internet of Things

K Suresh, M.Ramesh Patnaik

**Abstract:** To enhance the reliability of the link and guarantee deterministic channel access, IEEE 802.15 TG4e has introduced DSME as an amendment to IEEE 802.15.4. In this article, we analyze the throughput and energy consumption of DSME mechanism. Further, we propose optimization framework to find contention window (CW) that can enhance the aggregate utility and minimize the energy consumption of a device. Results prove that the performance of DSME is improved by 80% using the optimal setting of CW. The results are finally validated using ns-3.

**Keywords:** IEEE 802.15.4e, DSME, contention window.

## I. INTRODUCTION

With the increase in low cost and low power wireless sensor devices, green communication has revolutionized the Internet of Things (IoT). To enhance the networking capability of IoT, IEEE 802.15.4 introduces various amendments for wireless personal area networks (WPANs). Few of the standards recognized by IEEE 802.15.4 are ZigBee, IETF 6LoWPAN, Wireless HART and ISA100.11a because of their low power consumption [1]. The IEEE 802.15.4 operates in 2.4GHz of ISM bands. In industrial applications like food processing, wireless controlled area networks, transfer of large amount of data with less energy consumption shows a difference in the network performance. As the available channel time in IEEE 802.15.4 is common to all the devices, there is a performance degradation due to severe contention. To overcome this problem IEEE 802.15 task group introduces IEEE 802.15.4e as an amendment to IEEE 802.15.4 [6]. The new standard introduces five different MAC modes, among which Deterministic and Synchronous multi-channel Extension (DSME) is used to provide deterministic time slots and to improve the reliability of the network [5]. DSME uses multi-channel to enhance the throughput of the network.

All the devices in the network exploit unused periods of the channel time in DSME mode when it operates in beacon-enabled case [7]. The Access Point (AP) in DSME mode periodically broadcast the beacon and changes the channel according to a sequence. Thus, each device uses a reserved slot on the individual channel. However, in a dense network like IoT, the devices increase the contention in a reserved slot [14]. On the other hand, IoT is a heterogeneous network where devices have different priorities [1]. The major

problem in such a network is that every device accesses the channel starting with equal range of contention window. This results in increase in contention and few of the devices may not be given a chance to access the channel which leads to the degradation of the network performance.

There has been much work presented in the prior art to analyze the DSME mechanism. In [4], the authors proposed a new association scheme for conservation of energy. Authors in [8] used an optimization technique to improve fairness in the network. Dong et al. in [10] improved the DCF mechanism in a network of less density. From [11-12], authors change several MAC parameters to maximize the network performance. So far, the state-of-the-art has not considered the assessment of dense IoT network scenario. To the best of the authors' knowledge, this work considers the densest IoT scenario and improve its performance using optimal MAC settings i.e., using optimal contention window.

The article is organized as follows : Section II describes the device model for evaluating the IoT network's performance, energy consumption and optimization. The measurements are elaborated in section III. The paper summary is presented in Section IV, which summarizes the following:

- We evaluate the DSME performance in dense IoT scenario.
- The results are evaluated using optimal contention window for various network devices.

## II. NETWORK SCENARIO

We believe a completely connected and saturated network. The channel is error free and split into periodic slots. All nodes contend with DCF [2]. Before initiating the counter, the medium is listened for DIFS. The counter is picked from  $[0, W_0-1]$ .  $W_0$  is initialized to zero for each packet transmission, and is doubled to the maximum contention window ( $CW_{max}$ ) for collision [9]. An  $i$ th back-off argument is given by,

$$W_i = \begin{cases} 2^i \times W_0; \\ 2^m \times W_0; \end{cases} \quad (1)$$

Let  $s(t)$  and  $b(t)$  be represents the contention stage and contention value in a  $j^{th}$  slot [3]. The (DTMC) of DCF is shown in the Fig. 1.

Let  $b_{i,k} = \lim_{t \rightarrow \infty} P\{s(t) = i, b(t) = k\}$  represents the probability distribution,

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$$b_{i,0} = p_{c,j}^i b_{0,0} \quad (2)$$

$$b_{i,k} = \frac{W_i - k}{W_i} b_{i,0}$$

All the  $b_{i,k}$  in Eq. (2) is given by,

$$\sum_{i=0}^m \sum_{k=0}^{W_i-1} b_{i,k} = 1, \quad (3)$$

Therefore,

$$b_{0,0} = \frac{2(1-p_{c,j}^{R+1})(1-2p_{c,j})}{\left( (1-2p_{c,j})(1-p_{c,j}^{R+1}) + W_0(1-(2p_{c,j})^{m+1})(1-p_{c,j}) + W_0 2^m p_{c,j}^{m+1}(1-2p_{c,j})(1-p_{c,j}^{R-m}) \right)}. \quad (4)$$

The chance of sending a packet is,

$$\tau_j = \sum_{i=0}^m b_{i,0} = \sum_{i=0}^m p_{c,j}^i b_{0,0}. \quad (5)$$

Then, the probability of error in case of not receiving the packet is given by,

$$p_{c,j} = 1 - (1 - \tau_j)^{g-1}. \quad (6)$$

Let  $P_{tr,j}$  be transmission probability in a  $j^{th}$  slot,

$$P_{tr,j} = 1 - (1 - \tau_j)^g. \quad (7)$$

$P_{s,j}$  is the successfully communication of a packet in a  $j^{th}$  slot,

$$P_{s,j} = \frac{g \tau_j (1 - \tau_j)^{g-1}}{1 - (1 - \tau_j)^g}. \quad (8)$$

### A. Throughput

The saturation  $S_j$  can be computed as,

$$S_j = \frac{\left( \begin{array}{c} \text{Average information} \\ \text{transmitted in a mini-slot} \end{array} \right)}{\text{Average duration of a mini-slot}}, \quad (9)$$

$$= \frac{P_{tr,j} P_{s,j} E[P]}{(1 - P_{tr,j})\sigma + P_{tr,j} P_{s,j} T_s + P_{tr,j} (1 - P_{s,j}) T_c}$$

where  $E[P]$  is packet size,  $T_s$  and  $T_c$  are successful time and collision time,

$$T_c = T_s = T_{PS\_Poll} + DIFS + \delta. \quad (10)$$

### B. Energy consumption

In the DCF system, the energy consumption has divided into four parts of energy:

Therefore, power exhausted is given by

$$\eta_j = \frac{E_b + E_f + E_s + E_c}{P_{tr,j} P_{s,j} E[P]}. \quad (11)$$

The average energy of retrieving stage is ,

$$E_b = E[B] \sigma P_{idle}, \quad (12)$$

$$E[B] = \sum_{i=0}^R p_{c,j}^i (1 - p_{c,j}) \sum_{j=0}^i \frac{W_j - 1}{2}. \quad (13)$$

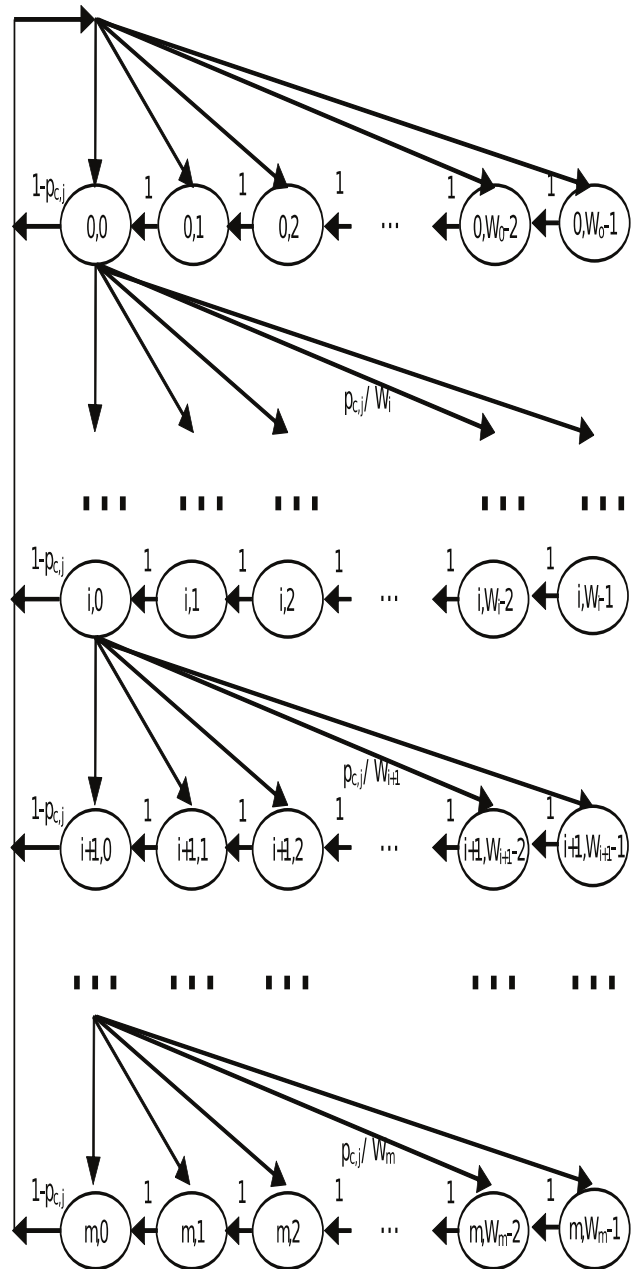


Fig. 1. DTMC model to find the transmission probability.

Therefore, the energy of sensing is given by,

$$N_i = \sum_{i=0}^R i p_{c,j}^i (1 - p_{c,j}). \quad (14)$$

$$E_s = P_{Tx} (T_{PS\_Poll} + T_{E[P]}) + P_{Rx} (T_s - T_{PS\_Poll} + T_{E[P]})$$

$$E_c = N_i [P_{Tx} (T_{PS\_Poll}) + P_{Rx} (T_c - T_{PS\_Poll})] \quad (15)$$

### C. Optimal contention window

Form equation (9),

$$S_j = \frac{1}{T_s - T_c + \sigma \frac{T_c [1 - (1 - \tau_j)^g] + (1 - \tau_j)^g}{g \tau_j (1 - \tau_j)^g}} \quad (16)$$

Since the all the timings in the above equation are constants, the throughput can be maximized and energy consumption can be minimized by maximizing the following equation,

$$\frac{n \tau_j (1 - \tau_j)^{(g-1)}}{\frac{T_c [1 - (1 - \tau_j)^g] + (1 - \tau_j)^g}{\sigma}} = \frac{n \tau_j (1 - \tau_j)^{(g-1)}}{\frac{T_c}{\sigma} - (1 - \tau_j)^g \left(\frac{T_c}{\sigma} - 1\right)}$$

Finding the first derivation of the above equation we get,

$$\tau_{opt} = \frac{1}{n} \sqrt{\frac{2\sigma}{T_c}} \quad (17)$$

Therefore, the DSME performance is maximized by using the optimal contention window which is given by,

$$W_{opt} = \frac{(1 - \tau_{opt})^{(g-1)}}{\tau_{opt} (2 - (1 - \tau_{opt})^{g-1})} \quad (18)$$

### III. RESULTS AND DISCUSSIONS

Each segment of analysis is gone forth with logical validations. The findings are validated with ns-3. The other analytical values used to obtain the analytical and simulation results are given in Table 1 and the rest are as per normal.

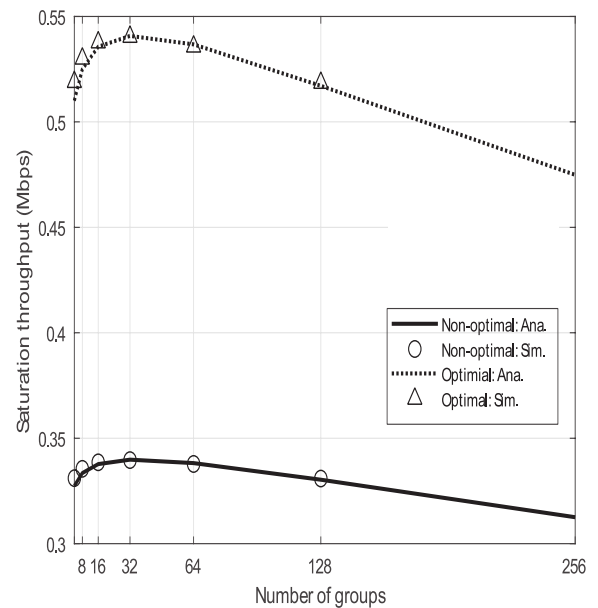
**Table 1. Parameters used for analysis**

Parameter	Value
Initial data rate	50Kbps
Delay	3 us
Symbol duration	12us
Slot time	56u s
Short interval	12u s
DCF interval	89 us
Transmission power	756 mW
Reception power	268 mW
Idle power	3 mW

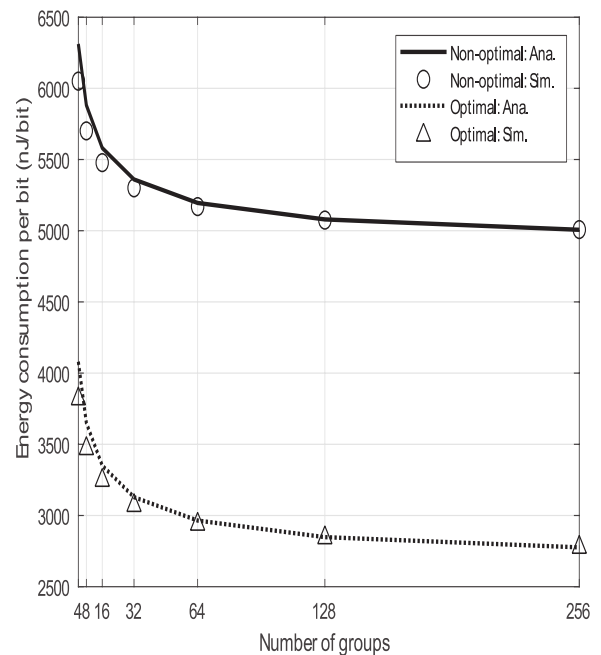
Figure 2 and Fig.3 demonstrate the DSME mechanism 's success for specific classes , i.e., for distinct number of DSME slots. We consider g systems of various groups K = category {8, 16, 32, 64, 128, 256}. It is found from this that DSME system efficiency is improved with community size change. Since variance in K reduces the size of the network per party, and reduces the conflict between them. Whereas for greater amounts of \$K\$ it is found that there is a small rise in energy usage and a steady decline in the throughput. The key explanation behind the trend is channel resource wastage. While the competition for greater amounts of \$K\$ is reduced, the systems enter the DCF state. This undesirable trend reduces the performance to depletion. But the system would be idle during the back-off period, so uses less fuel. So the electricity intake will not increase dramatically. The practicable approach is achieving the maximum outcome of the DSME process is achieving the optimum value of the period of dispute. Therefore, the findings specifically indicate substantial change in DSME process efficiency as contrasted with the non-optimal contention window utilizing

optimal contention system.

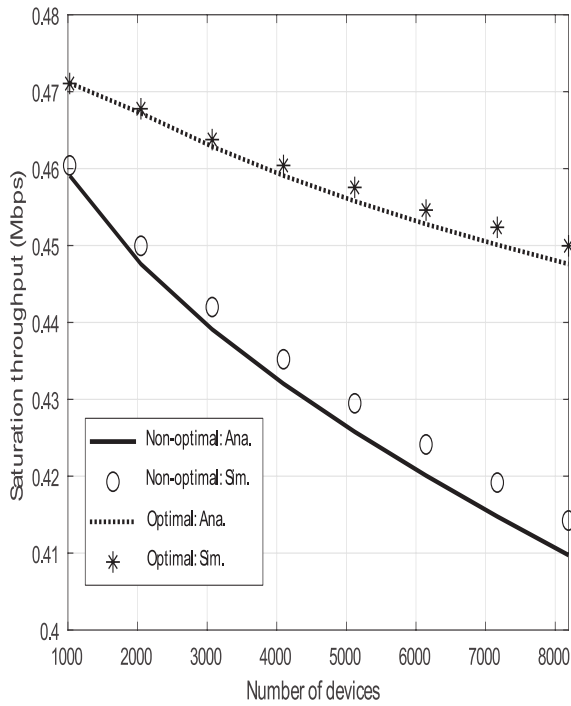
Figure 4, Figure 5 Display DSME system output utilizing maximal contention window. Since the 4e specification recognizes broad networks, the DSME output is evaluated for the optimum value of contention window In Fig for a network of size g=8192 networks. 4 and Fig.5, the DSME process is tested using the maximal conflict period and the effects are contrasted with the non-optimal non-optimal containment range. It is observed that the optimum conflict period is marked by an improvement in the throughput and deterioration of energy usage.



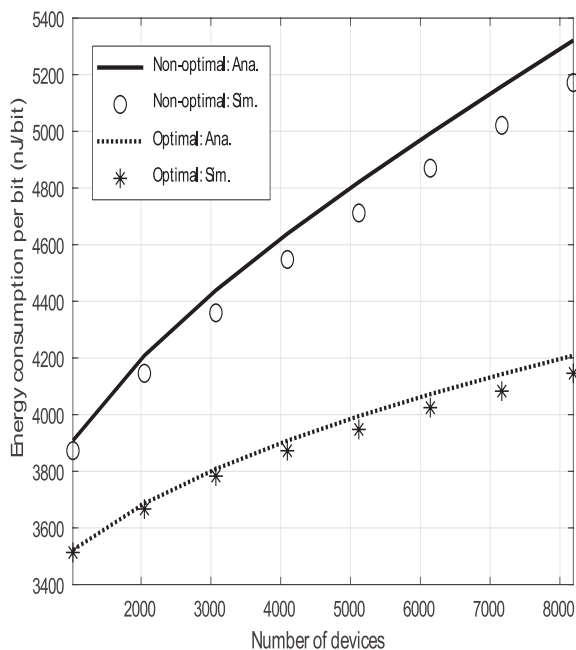
**Fig. 2 Throughput for different DSME slot (Each DSME slot is consider as a group)**



**Fig. 3 Energy consumption for different DSME slot (Each DSME slot is consider as a group)**



**Fig. 4 Saturation Throughput Vs. Network size**



**Fig. 5 Energy Consumption Vs. Network size**

## IV. CONCLUSION

A novel scheme is suggested in this paper to determine the optimum window of conflict that can substantially increase the energy usage and the throughput. We proposed a basic mathematical model for testing the IEEE 802.15.4e DSME system throughput and energy usage, through adjusting Bianchi's DCF model. From the findings described scheme improves the DSME process dramatically. Use simulations in ns3, all statistical work is checked last.

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