An Efficient Backoff Scheme in Wireless Sensor Networks

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***Abstract*—The IEEE 802.15.4 protocol is designed to provide for connecting low data rate devices with low-power in wireless personal area network (LR-WPAN). In IEEE 802.15.4, a slotted carrier sensing multiple access with collision avoidance (CSMA/CA) algorithm is employed to coordinate a large number of sensor devices. Energy consumption requirements make it to use fewer number of backoffs, which adversely increases collisions, resulting in degradation of energy consumption. In this paper, we present a novel scheme to improve both network throughput and energy efficiency. We develop a Markov model for the proposed scheme with the provision of mathematical analysis, which is validated via experiments using ns-2 simulator. It is shown that the proposed scheme significantly enhances the performance in respect of both network throughput and energy efficiency.**

***Index Terms*—IEEE 802.15.4, CSMA/CA, energy efficiency, backoff algorithm.**

I. Introduction

With the help of advances in micro sensing technology, wireless sensor networks (WSNs) are widely and quickly deployed in various application scenarios such as environmental and agricultural monitoring, industrial control and sensing, energy management, home automation, and so on. The WSNs consist of a large number of distributed sensor nodes, which are usually battery powered with almost no computational capacity. Since frequent replacement of the batteries deployed in wide area is neither feasible nor cost effective, saving energy consumption is a critical factor to prolong the network lifetime. Unlike many other wireless communication standards which mainly focus on yielding high network throughput, IEEE 802.15.4 low-rate wireless personal area network (LR-WPAN) [1] standard is designed to have the properties of low energy consumption, low cost and low data rate for a short range transmission. Therefore this standard is considered as the best suited candidate and an enabling technology for many of the resource constrained WSNs. In order to increase energy efficiency, unlike WLAN in which a node continuously senses the channel, LR-WPAN conducts sporadic clear channel assessments (CCAs) by sensing the channel after a random backoff procedure finishes. This enables the node to switch to low-power mode during random backoff delay. Moreover, it increases backoff exponent (BE) after every CCA failure and resets it to the minimum (MinBE) value upon data transmission or packet drop, which is incompetent to resolve the high contention level.

In this paper, in order to further enhance throughput and energy efficiency in IEEE 802.15.4 networks, we propose a novel scheme called Efficient Backoff (EB). The EB chooses the backoff range according to the CCA's result to avoid unnecessary sensing the ongoing transmission, such that energy consumption is decreased.

II. Overview of the IEEE 802.15.4 standard

The IEEE 802.15.4 supports two modes of operation, beacon and non-beacon enabled modes. In non-beacon enabled mode, a simple unslotted CSMA/CA is used for channel access and data transmission. Prior to data transmission, the node applies a random backoff delay chosen uniformly from a range of $[0, 2^{BE} - 1]$. After backoff delay, the node conducts CCA. If channel is sensed idle, it transmits the data; otherwise, the BE is increased by one and backs off stage starts again.

In beacon-enabled mode, the frame structure is organized as a superframe, which is a time period between two consecutive beacons that are sent by the coordinator. Beacon frame transmitted periodically by coordinator provides the information related to the superframe and synchronizes all nodes in the WSNs. The superframe is divided into an active period and an inactive period. During inactive period, a coordinator or sensor nodes do not interact with each other and go to low-power mode. Active period consists of contention access period (CAP) and contention free period (CFP). During a CAP, a node competes for channel access by using slotted CSMA/CA that operates as a unit of slot time called backoff period (BP). On the other hand, a coordinator can designate specific slots for certain nodes to have contention free transmission, so that quality of services and low latency traffics are delivered during CFP. In a slotted CSMA/CA, a node manages 3 variables; NB, CW, and BE, which respectively indicate the number of backoffs that represents the number of attempts to access the channel, the number of BPs that has to be cleared in the channel before a transmission starts, and backoff exponent that represents how many BPs the node needs to wait. At first, the node selects a random backoff delay ranging from $[0, 2^{BE} - 1]$ during which it goes to low-power mode. After completing

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its random backoff delay, the node needs to ensure that the channel is free before attempting to transmit the data. This is achieved by performing CCAs to check idleness of the channel and decreasing the CW value by one when channel is not used by any other nodes. The channel needs to be idle for two consecutive CCA operations to start a transmission. If channel is sensed busy by any of two CCAs, the node resets its CW value to its initial value of 2, and doubles next backoff range by increasing the BE by one until it reaches the maximum value (aMaxBE). Also, the NB value is increased by one for every CCA failure. If the NB reaches its maximum value (macMaxCSMABackoffs), the node drops the data and ceases the transmission.

III. Related works and Motivations

Designing the energy efficient protocol is the main challenge in WSNs since sensor nodes need to restrict power consumption. The loss of energy is primarily caused by collisions, protocol overhead, idle listening, and overhearing. In this section, we review the previous works for enhancing performance of the medium access control (MAC) protocols of IEEE 802.15.4. Then, we explain the contributions of this paper.

A comprehensible and intuitive Markov model extension by considering acknowledgment (ACK) transmission is presented in [2]; they showed that MAC parameters should be carefully selected to achieve a better network performance. A new analysis taking retransmission into consideration is presented in [3], which adopted approximation methods rather than modeling the exact behaviors of IEEE 802.15.4 CSMA/CA. A modified model including limited retries for retransmission is proposed in [4]. This model is an extension from [2] with consideration of independent channel access probabilities in the every backoff stage. Park et al. [5] demonstrate the hybrid multiple access protocol in the IEEE 802.15.4. They propose hybrid MAC by connecting two Markov chain models of CAP and CFP for non time-critical data transmission and time-critical data transmission, respectively. Cao et al. [6] develop an analytical model which considers both the case of with or without retransmission based on periodic traffic scenario. This model is verified through extensive simulations to capture CSMA/CA algorithm performance accurately. Guglielmo et al. [7] provide an analytical model for a time slotted channel hopping CSMA/CA with consideration of capture-effect. They validate the model via simulations and measurements in testbed that capture-effect plays a significant role for improving performance experienced by nodes. However, the traditional CSMA/CA is not aware of the exact remaining time of ongoing data transmission by other nodes after CCA fails. Therefore, there is a possibility that the node selects the next random backoff delay less than the expected completion time of the current transmission, which leads to an unnecessary extra CCAs, causing degradation of energy performance. This problem is addrsesed in [8], which proposes a scheme in which a special preamble is attached in front of data frame. With the help of this, it can detect when the data starts and attempts to sense the first slot of ongoing transmission. Once the first slot of ongoing transmission is sensed by CCAs, it estimates the remaining time of ongoing transmission. But, [8] is inefficient, because the setting of backoff range is too high to achieve smaller delay and they need extra energy to transmit the preamble. In addition, they presented the efficiency of the algorithm via simulation without providing thorough mathematical analysis. Dahham et al. [9] propose an effective backoff algorithm to reduce collisions and improve energy efficiency. It updates the contention window size according to the probability of collision and uses temporary backoff within the actual backoff period. However, the probability of collision cannot accurately reflect the contention level for channel access. In [10], the authors suggest altering the $aMaxBE$ and $MinBE$ values based on the consecutive successful and failed transmissions. That is, it increases (or decreases) the $aMaxBE$ and $MinBE$ values by one until reaching their maximum (or minimum) value after two consecutive successful (or failed) transmissions. Therefore, reducing backoff value after consecutive collisions for high traffic loads leads to more collisions and degrades the performance of energy consumption. Patel et al. [11] suggest a scheme that implements new extra CCAs operation to reduce energy efficiency. This method takes two, three, or four consecutive CCAs to determine the current channel condition. While this scheme works well for sparse networks where there are few competing nodes, its performance for energy consumption is degraded for densely populated networks since as traffic load or the number of nodes increases the possibility of data collision among sensor nodes increases as well.

From previous work, [8], we conjecture that if the backoff value is properly selected after ongoing transmission, then the energy is to be substantially saved by avoiding unnecessary CCAs. This is the motivation of this work, whose contributions are summarized as followings. First, we propose a novel EB scheme to improve the network throughput and energy efficiency of IEEE 802.15.4 MAC protocol. EB is an enhancement from [8], reducing the redundancy of backoff by shifting backoff range. To avoid unnecessary sensing the ongoing transmission, EB adaptively selects backoff range upon CCAs results. Secondly, we build a Markovian model reflecting the proposed scheme, whose performance is rigorously analyzed along with validations by extensive experimental simulations.

IV. System model

IEEE 802.15.4 supports two modes of operation, beacon and non-beacon enabled. We only consider beacon enabled mode, in which the superframe is divided into CAP, CFP, and inactive period. During CAP, a node uses slotted CSMA/CA that operates as a unit of slot time, called backoff period (BP), which represents a slot time or a frame length. In order to evaluate MAC protocol performance, we neglect CFP and inactive period so that the superframe duration is fully occupied by CAP. We assume that the data arrive at each node for uplink transmission according to a Poisson process with λ, then the arrival rate γ in a slot time T_{slot} is given by

$$\gamma = \int_0^{T_{slot}} \lambda e^{-\lambda t} dt. \tag{1}$$

Since we aim to develop an efficient CSMA/CA scheme, we consider single-hop uplink data transmission from N number of contending nodes. We assume that each node is non-saturated, the transmission channel is error-free, and no retransmission is allowed after a packet collision. Even though our model is simplified, it can be extended to more realistic scenarios without loss of generality.

V. Proposed scheme

Resources are constrained in the WSN, therefore CSMA/CA algorithm is required to use a small range of BE. Since the BE determines the number of backoff slots, the node accordingly waits accessing the channel; the higher the BE, the longer the backoff delay, leading to greater energy consumption. For this reason, a smaller BE is adopted in IEEE 802.15.4 standard, which however increases the possibility of collision. A sensor node with data to send chooses a random backoff delay ranging from $[0, 2^{BE} - 1]$. After finishing the backoff procedure, it performs CCAs to assess the channel busy. If the channel is busy, it doubles the backoff range until the BE reaches its maximum value.IEEE 802.15.4 CSMA/CA conducts two CCAs, $CCA1$ and $CCA2$; $CCA2$ is only operated right after $CCA1$ succeeds. If any of these CCAs fails, the node gets into backoff with its range doubled, i.e., $[0, 2^{BE+1} - 1]$ for the next stage. However, since the starting value of backoff range is fixed to 0 in the standard, there is a chance that small value of backoff is selected, thereby the backoff ends before the end of ongoing transmission, causing higher energy consumption due to unnecessary additional CCAs. In figure 1, it displays the simple transaction among nodes in the WSNs for standard and EB. When the second node finishes its backoff procedure, it senses the channel busy by conducting CCA operation as the first node sending its data. Again, the second node resumes to backoff procedure immediately. Since the random backoff can be any value between range of $[0, 2^{BE+1} - 1]$, it can draw smaller backoff number. Therefore the second node again senses an ongoing transmission and performs a meaningless CCA operation which leads to the energy degradation. We conjecture that if the backoff value is selected after ongoing transmission, then the energy is to be substantially saved by avoiding unnecessary CCAs. This is the motivation in devising EB, where we set the starting value of backoff interval to the expected remaining time of other's ongoing transmission after $CCA1$'s failure, which is calculated as

$$d_1 = \alpha_d E[L_{data}] + (1 - P_{col})(L_{ack} + L_{idle}) + \alpha_a E[L_{ack}] \tag{2}$$

where L_{data} and L_{ack} represent the sizes of data and acknowledgement, respectively; L_{idle} is the length of idle period between data and acknowledgement, equal to 1; P_{col} is the

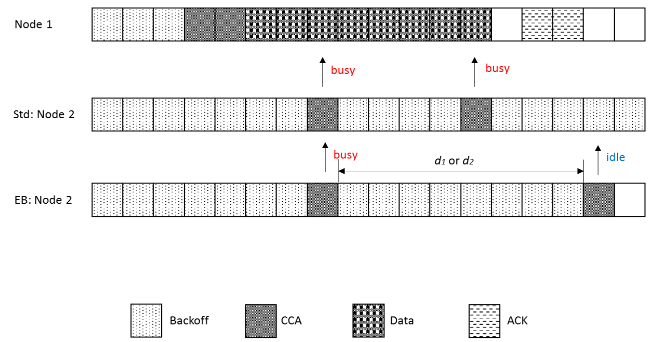

Fig. 1. Transmission scenario of both standard and EB scheme

probability of collision within the network; α_d and α_a are the probabilities of sensing data and acknowledgement for $CCA1$, respectively, and computed as $\alpha_d = L_{data}/\{(L_{data} + (1 - P_{col})L_{ack})\}$, $\alpha_a = (1-P_{col})L_{ack}/\{(L_{data}+(1-P_{col})L_{ack})\}$.

There are only two cases when the ongoing transmission is sensed by $CCA2$, namely when $CCA1$ senses an empty slot just before the data transmission by other nodes, or an empty slot between the data and acknowledgement transmission. Thus, the expected remaining time of other's ongoing transmission for $CCA2$ is calculated as

$$d_2 = \beta_d E[L_{data}] + (1 - P_{col})(L_{ack} + L_{idle}) + \beta_a E[L_{ack}] \tag{3}$$

where β_d and β_a are the probabilities of sensing data and acknowledgement for $CCA2$, respectively, and computed as $\beta_d = 1/(2-P_{col})$, $\beta_a = (1-P_{col})/(2-P_{col})$ and explained in section VI. Concludingly, depending on the results of CCAs, EB sets the backoff range to $[d_1, 2^{BE+1} - 1]$ instead of $[0, 2^{BE+1} - 1]$ employed in the standard when $CCA1$ fails, and $[d_2, 2^{BE+1} - 1]$ when $CCA2$ fails. Thereby it prevents having more unnecessary CCAs and energy consumption.

VI. Analytical model

In this section, we develop an analytical model for our proposed EB scheme. The proposed scheme is characterized by two-dimensional Markov chain $\{s(t), c(t)\}$ as shown in Figure 2. $s(t)$ is the stochastic process representing the backoff stages $s(t) \in \{0, 1, ..., m\}$ or the transmission stage $(s(t) = -1)$, where m is the maximum number of CSMA backoffs defined by *macMaxCSMABackoffs* in the standard. And $c(t)$ is the stochastic process representing the backoff counter $c(t) \in \{0, 1, ..., Wi - 1\}$, where W_i is the backoff window, initially $W_0 = 2^{MinBE}$ and incremented by double as $W_i = W_0\, 2^{min(aMaxBE - MinBE,\ i)}, i \in [0, m]$; and *MinBE* and *aMaxBE* represent the minimum and maximum value of backoff exponent, respectively, and $(c(t) = -1)$ and $(c(t) = -2)$ correspond to $CCA1$ and $CCA2$, respectively.

By letting α be the probability of assessing channel busy for $CCA1$, and β the probability of assessing it busy for

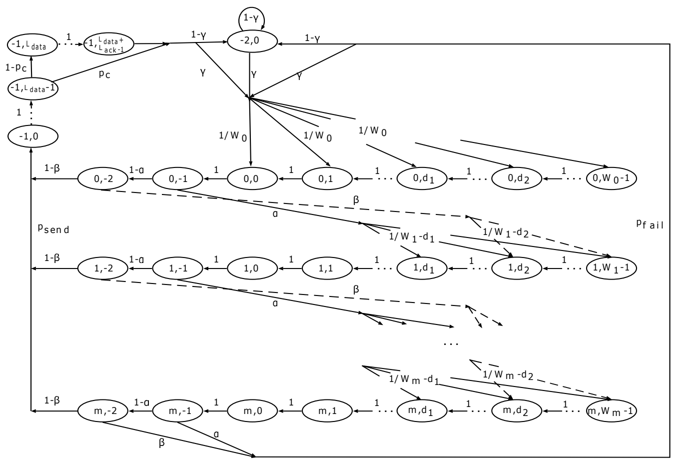

Fig. 2. Markov model of the Efficient Backoff scheme

$CCA2$ given that it was idle for $CCA1$, the state transition probabilities in Figure 2 are given by

$$P\{i,k|i,k+1\} = 1,\ i \in [0,m],\ k \in [-1, W_i-2] \tag{4}$$
$$P\{0,k|i,0\} = P_{succ}\gamma/W_0,\ i \in [0,m-1],\ k \in [0,W_0-1] \tag{5}$$
$$P\{i,k|i-1,0\} = \alpha/(W_i-d_1),\ i \in [1,m],\ k \in [d_1, W_i-1] \tag{6}$$
$$P\{i,k|i-1,0\} = (1-\alpha)\beta/(W_i-d_2),\quad i \in [1,m],\ k \in [d_2, W_i-1] \tag{7}$$
$$P\{0,k|m,0\} = \gamma/W_0,\ k \in [0, W_0-1] \tag{8}$$
$$P\{-1,k+1|-1,k\} = 1,\ k \in [0, L_{data}-1] \tag{9}$$

where P_{succ} is the probability of assessing channel idle for two consecutive CCAs given by $P_{succ} = (1-\alpha)(1-\beta)$.

Equation (4) states that the backoff counter decreases by one for each slot time, and equation (5) represents the probability of returning back to initial backoff stage after transmitting a data. Equation (6) presents the probability that a node senses the channel busy for $CCA1$, thus entering the next backoff stage with a selection of backoff delay from a range $[d_1, W_i-1]$, and equation (7) gives the probability that a node senses the channel busy for $CCA2$, thus selecting a random backoff delay from $[d_2, W_i-1]$. The probability of starting a new transmission after reaching the maximum backoff stage is described in equation (8), and the probability of data being transmitted is given in equation (9). Moreover, when data transmitted by a node is collided with other's transmission, we assume that it takes 3 slot times to determine a collision.

Let $b_{i,k}$'s be the steady state probabilities of the Markov chain, i.e., $b_{i,k} = \lim_{t\to\infty} P\{(s(t) = i, c(t) = k\}$ where $i \in [-2, m]$, $k \in [-2, \max(L^{'}-1, W_i-1)]$, and $L^{'} = L_{data} + L_{ack} + L_{idle}$. Then by combining equations (4) through (9), we obtain $b_{i,k}$ as

$$\begin{aligned}
b_{i,0} &= P_{busy}^{i} b_{0,0} \quad, i \in [0,m] && (10)\\
b_{i,k} &= P_{busy} b_{i-1,0} \quad, i \in [1,m],\ k \in [0, d_1-1] && (11)\\
b_{i,k} &= \{\alpha(W_i-k)/(W_i-d_1) + (1-\alpha)\beta\} b_{i-1,0}, \\
&\qquad i \in [1,m],\ k \in [d_1, d_2-1] && (12)\\
b_{i,k} &= \{[\alpha/(W_i-d_1) + (1-\alpha)\beta/(W_i-d_2)](W_i-k)\} \\
&\qquad \cdot b_{i-1,0} \quad, i \in [1,m],\ k \in [d_2, W_i-1] && (13)\\
b_{-2,0} &= (1-\gamma) b_{0,0}/\gamma && (14)
\end{aligned}$$

where $P_{busy} = \alpha + (1-\alpha)\beta$ is the probability of channel being busy. Summing all the steady state probabilities

$$\sum_{i=0}^{m}\sum_{k=0}^{W_i-1} b_{i,k} + \sum_{i=0}^{m} b_{i,-1} + \sum_{i=0}^{m} b_{i,-2} + \sum_{i=0}^{L'} b_{-1,i} + b_0 = 1, \tag{15}$$

we obtain the initial steady state probability $b_{0,0}$ as

$$\begin{aligned}
b_{0,0} = 1/\{&(W_0+1)/2 + ((1-P_{busy}^{m+1})/(1-P_{busy}))(d_1+2-\alpha \\
&+ L'P_{succ}) - d_1 + (d_2-d_1)(1-\alpha)\beta((1-P_{busy}^{m})/(1-P_{busy}) + \\
&\sum_{i=1}^{m} P_{busy}^{i-1}/2[\alpha(W_i-d_1+1) + \beta(1-\alpha)(W_i-d_2+1)] + (1-\gamma)/\gamma\}.
\end{aligned} \tag{16}$$

Let ϕ be the probability that a node attempts to sense the channel at a random slot time, then

$$\phi = \sum_{i=0}^{m} b_{i,0} = (1-P_{busy}^{m+1})/(1-P_{busy}) b_{0,0}. \tag{17}$$

Let P_{send} be the probability that a node successfully seizes the channel hence transmits data, then it is represented by

$$P_{send} = (1-(1-\phi)^N) P_{succ}. \tag{18}$$

Let P_s be the probability of successful transmission, i.e., the probability that a node assesses the channel idle for two consecutive time slots, and the others not; and let P_{col} be the probability of collision within the network. Then they are expressed as

$$\begin{aligned}
P_s &= N\phi(1-\phi)^{N-1} P_{succ} && (19)\\
P_{col} &= 1 - P_s/P_{send}. && (20)
\end{aligned}$$

The probability of assessing channel busy for $CCA1$, α, equals the probability that at least one of the remaining $N-1$ nodes sends the data which is obtained by [2]

$$\alpha = \alpha_d + \alpha_a = P_{succ}(1-(1-\phi)^{N-1})(L_{data} + L_{ack}(1-P_{col})). \tag{21}$$

Similarly, the probability of assessing channel busy for $CCA2$, β, counts the probabilities that at least one of the remaining $N-1$ nodes starts transmitting during $CCA2$ and $CCA1$ senses empty slot between data and acknowledgement by the other nodes, and is expressed by

$$\beta = \beta_d + \beta_a = (2-P_{col})/(2-P_{col}+1/(1-(1-\phi)^N)). \tag{22}$$

TABLE I
SIMULATION SETTINGS

	Parameter	Value
Data size	L_{data}	10 slots (100 Bytes)
	L_{ack}	2 slots (11 Bytes)
	L_{idle}	1 slot
	1 slot	0.32 ms
	ACK timeout	3 slot
CSMA/CA setting	*MinBE*	3
	aMaxBE	5
	macMaxCSMA	4
Power (mW)	Rx	40
	Tx	30
	CCA	40
	idle	0.8

Three values of α, β and ϕ in equations (17), (21) and (22) are sufficient to drive performance metrics in our work, namely network throughput and energy consumption, and we exploited Matlab tool to numerically solve these nonlinear equations.

VII. PERFORMANCE EVALUATION

A. Throughput and Energy Analysis

In this section, we analyze our Markov model in terms of network throughput and energy consumption. The network throughput is defined by the amount of data successfully delivered to the destination, thus expressed by

$$G = P_s L_{data} R \tag{23}$$

where the transmission rate $R = 250$ Kbps for IEEE 802.15.4, equivalently $R = 10$ byte/0.32ms, where 0.32ms corresponds to a slot time. To compute energy consumption, we need to derive the percentage of time that a node stays in each of transmitting (Tx), receiving (Rx), sensing (CCA), and idle state; or their corresponding probabilities of residing in respective states, namely P_{tx}, P_{rx}, P_{cca}, and P_{idle}. All these probabilities can be represented in terms of ϕ, P_{succ} as followings:

$$P_{tx} = L_{data}\phi P_{succ} \tag{24}$$
$$P_{rx} = (L_{idle} + L_{ack})(1 - p_c)\phi P_{succ} \tag{25}$$
$$P_{cca} = \phi + \phi(1 - \alpha) \tag{26}$$
$$P_{idle} = 1 - P_{tx} - P_{rx} - P_{cca} \tag{27}$$

where $p_c = 1 - (1 - \phi)^{N-1}$ is the probability of collision.

Then the total energy consumption is computed as the sum of the probabilities of each state multiplied by its corresponding energy consumption, and becomes

$$E = P_{tx}E_t + P_{rx}E_r + P_{cca}E_{cca} + P_{idle}E_{idle}. \tag{28}$$

B. Experimental Results

Our proposed scheme is experimented by using a discrete event ns-2 simulator to validate our analysis derived in section VI. A WSN is assumed to consist of 30 and 50 nodes, each of which transmits data to a coordinator. Table I summarizes the rest of system parameters that are used in simulation and analysis. Suppose $CCA1$ fails, then the remaining

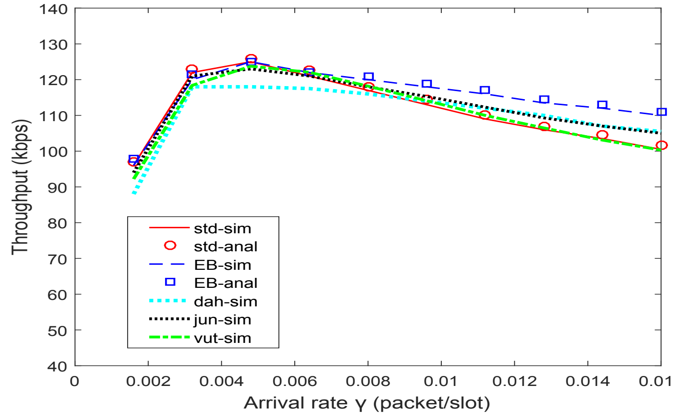

Fig. 3. Network throughput of 30 nodes under different loads

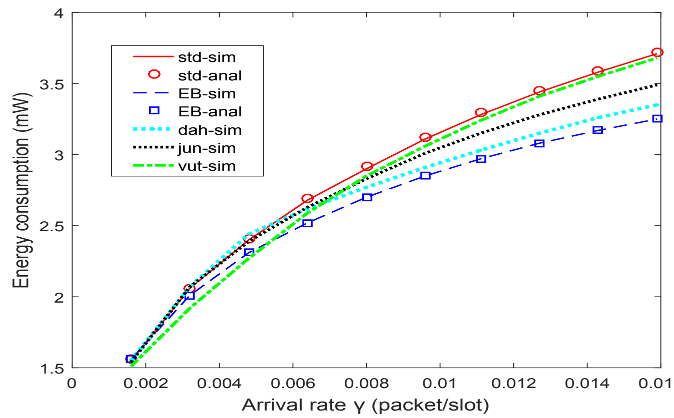

Fig. 4. Energy consumption performance of 30 nodes under different loads

time of ongoing transmission is uniformly distributed, hence $E[L_{ack}] = (L_{ack} - 1)/2$ and $E[L_{data}] = (L_{data} - 1)/2$. Since L_{ack} and L_{idle} are respectively sized one and two, the second term in equation (2) can be taken as a fixed value, say 2, and the third term is approximated to zero. Then equation (2) reduces to $d_1 = (L_{data} - 1)/2 + 2$ which is sized to a fixed value 7 slots. P_{col} presented in β_d and β_a in equation (3) cannot be practically learned since it substantially depends on application scenarios. In our simulations, we select P_{col} from a range of $[0.01, 0.4]$. With this selection, d_2 in equation (3) is approximated to 9. Although d_2 is not accurately estimated, the performance of our scheme is better than IEEE 802.15.4 standard since the number of unnecessary channel accesses are reduced. Figure 3 displays the comparison between the standard and the proposed strategy called EB, and [9], [8], and [10], which are named dah, jun, and vut in the figure, respectively, in terms of network throughput as a function of traffic load. In all cases, the analysis based on our Markov model matches quite well with the simulation results, essentially for a whole range of traffic load, only with a small mismatch of around 2% for a high traffic load. Moreover, EB represents better throughput performance than the standard, [9], [8], and [10] for a whole range of traffic load. The improvement of

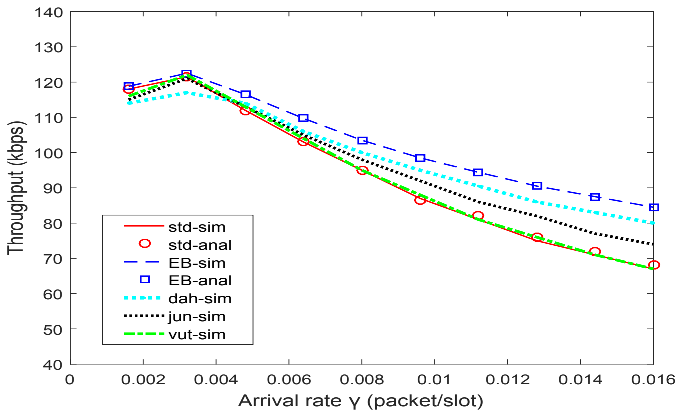

Fig. 5. Network throughput of 50 nodes under different loads

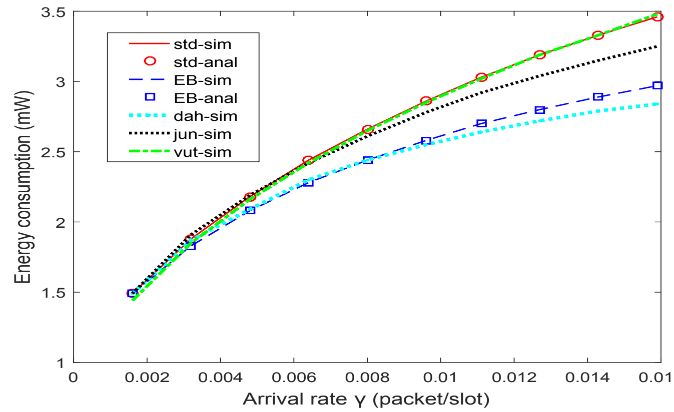

Fig. 6. Energy consumption performance of 50 nodes under different loads

proposed scheme owes to the reduction of the number of unnecessary backoffs and CCAs. The figure shows that EB enhances the network throughput up to 10% over standard and [10]; and 5% over [8] and [9]. Figure 4 depicts the comparison of energy consumption among the strategies for different values of γ. Our analysis almost completely catches up the simulation results. When lightly loaded, there is no difference of energy consumption among all strategies, since all of them experience substantially no collision. As shown in this figure, as the congestion level increases as the increase of traffic load, however, the possibility of data collision among competing nodes for channel access increases, and the energy efficiency of proposed scheme is highlighted. The reduction of energy consumption of proposed scheme is again due to the reduction of the number of unnecessary CCAs, which results in the energy saving by 9% for EB compared with the standard and [10], 6% over [8], and 3% over [9], respectively. Figure 5 shows the comparison of network throughput for 50 nodes among standard and 4 strategies mentioned before. In the same way, EB outperforms the standard, [10], [8], and [9] as the congestion level increases. For the lower traffic load, [9] performs the worst among all strategies due to its backoff window selection. The figure 5 shows that EB enhances the network throughput up to 20% over standard and [10]; and 13% over [8]; and 6% [9]. Figure 6 displays the energy consumption of all strategies and standard for 50 nodes under different traffic load. As shown in the figure, energy efficiency for EB over standard and [10] is up to 16% , and 9% over [8] as the increase of traffic load. For loaded traffic, [9] shows 4% better performance than EB in terms of energy consumption due to its selection of backoff range.

VIII. Conclusion

In this paper, in order to enhance throughput performance and energy efficiency for IEEE 802.15.4 WPAN, we propose a new scheme, called Efficient Backoff (EB), and develop its Markov model along with mathematical analysis. Also, to validate our model and analysis, the proposed scheme is sufficiently experimented using ns-2 simulator. The performance of the proposed strategy EB is compared with the standard both via analysis and simulation. It shows that all of our analysis for the standard and the proposed scheme match quite well with simulation results for both throughput performance and energy efficiency. The EB shows better performance than the standard and previous works for a whole range of traffic load, especially its improvement is highlighted as the increase of traffic load.

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