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IMPACT OF SLEEPING MECHANISM ON GAME BASED CR-MAC PROTOCOL PERFORMANCE

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Abstract. *With the development in new communication technology, design requirements are not just focused on energy efficiency, but also on good QoS (Quality of Service). Energy efficiency of a wireless network is a well researched topic. There are many solutions proposed for wireless networks to increase the energy efficiency and QoS. In the game, CR based MAC protocol, a node selects the contention window (CW) size as per the selected strategy. Later, a node will try to attend the transmission once the contention window counter (CC) reaches to zero. However, during the contention window counter (CC) decrement a node unnecessarily listen to channel and consumes energy. In this paper, a method is proposed for game-based MAC protocol to power off the radio during the execution of backoff algorithm. The proposed scheme has been tested with numerical analysis and supports our intuitions. With numerical results it is projected that game-based MAC protocol has improved energy efficiency of overall network by 85% to 95%.*

Keywords: Sleeping mechanism, CR-MAC protocol, Game theory, Wireless networks

1. Introduction.

Wireless networks are mainly categorized as distributed and centralized networks as shown in Figure 1. Both networks have their own merits and demerits. However, decentralized networks are gaining popularity due to its flexibility in implementation. On the other hand, centralized networks have better control over the network resources with full optimization.

Felegyhazi and Hubaux [1] and Dudhedia and Ravinder [2] have presented the application of game theory to cognitive radio based wireless network (CRWN). Dudhedia and Ravinder [2] have optimized the network performance using game theory at the MAC layer. Here, all nodes will convert MAC problem into games and play with three basic strategies: small, medium, and large. These strategies are based on different contention window sizes such as small (0-127), medium (0-511), and large (0-1023). With these different strategies, Dudhedia and Ravinder [2] were able to get the optimized network performance. The aforementioned method poses a possibility to further reduce the energy consumption. As shown in Figure 2, energy consumption pattern is divided into many parts: useful energy, not-useful energy and possible to reduce energy consumption further. Transmission and receiving are essential part of communication. Whatever energy

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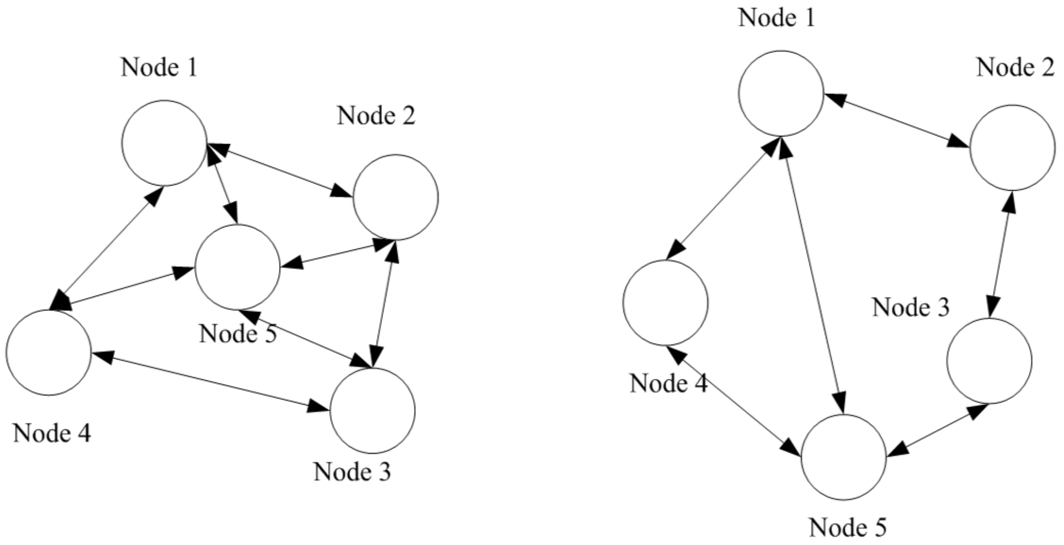

FIGURE 1. Centralized versus distributed network

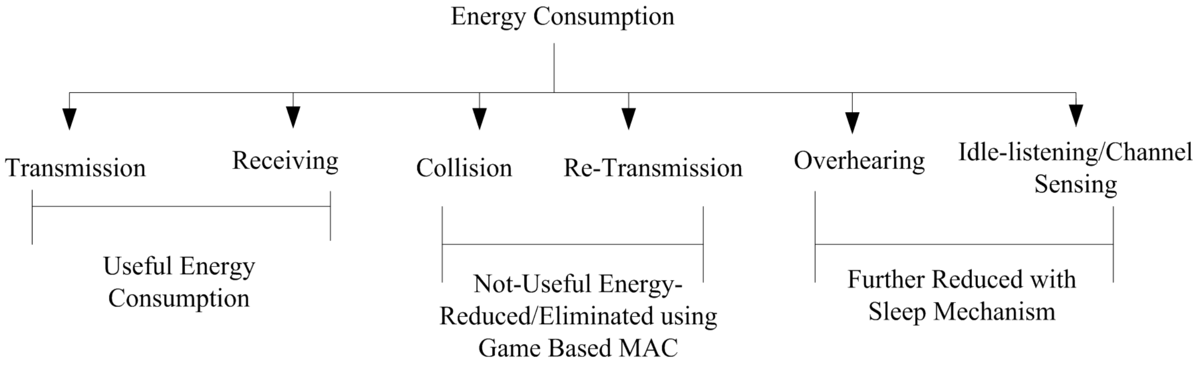

FIGURE 2. Energy consumption pattern

is spent in transmission and receiving is useful. To make any communication or network energy efficient, it is necessary to reduce the unnecessary collision and hence retransmission. Also, if radio is not off after the communication, it will consume unnecessary energy in overhearing and idle listening. Therefore, to achieve optimized energy efficiency, it is important to reduce the non-useful, overhearing, and idle listening to zero or at least to minimum level.

In many cases, CRWN is decentralized. Related work shows application of game theory to CRWN is useful. MAC protocols are designed to share dynamic spectrum among primary and secondary users.

MAC output is controlled by a binary exponential back-off (BEB) algorithm. The BEB model must therefore be researched to allow a network level output to access an individual node. In this paper, the main emphasis is on the analysis and effect on network efficiency with sleep mechanism of the binary exponential back-off (BEB) algorithm. In BEB, the range of contention window is defined as $CW_0 = (0, 1, \ldots, CW_0 - 1)$, and CW_0 is the minimum contention window size as defined in [3]. A node can select the value of CW from abovementioned range and transmit a packet after waiting for CW slots. The contention window is 'slot time' used as time unit. In backoff algorithm (BA), this is a very basic unit of time. The data transmission or data receiving slots are multiple of this basic unit time.

Countless MAC layer protocols exist for energy-efficient networks, especially sensor networks, such as S-MAC and T-MAC protocols [4,5]. S-MAC protocol is a known wireless sensor-MAC protocol. Wireless nodes with energy sources are constrained such that the S-MAC has adopted the function of the sleeping cycle. Like S-MAC, T-MAC has introduced a variable data traffic dynamic sleeping interval. Their back-off algorithm is however based on the MAC protocol IEEE 802.11, which uses a great deal of resources. The backoff algorithm, which uses energy during idle listening, seldom requires a node in the idle listening mode. The IEEE 802.15.4 MAC protocol slotted CSMA/CA mechanism can be incredibly energy-efficient. It does however have such limitations such as dense networks rigidity and application-specific parameters (small scale networks, low throughput, etc.) as shown in [6]. Zheng et al. [7] have proposed the algorithm to measure the idle listening sleep period during the backoff algorithm implementation. Their methodology is focused on the channel's mathematical research. However, their model lacked many realistic assumptions such as unsaturated traffic, freezing effect, and re-try limit. In addition, for dense networks, it was not adaptable. In [8] authors have presented an MAC protocol for CRWN with detailed simulation study. Their protocol improves the network performance by 36% to 40% and compared to slot aloha and TDMA based MAC protocols, respectively. In [9], author has proposed a cooperative based approach to improving the network performance. In [10], authors proposed a new MAC protocol based on existing protocols to improve the network performance. In [11], authors have presented the Markov chain based model to capture the stochastic behaviour of SU and PU to identify the network performance. They carried out the theoretical calculation to study the Nash equilibrium behaviour, finding the social optimal solution by using their pricing policy. Their energy saving sleeping strategy had achieved the optimized social solution for the network. Majority of the work defined using game theory but the gaps are identified with respect to following aspects.

- Many games theoretical approaches are proposed but only for a single channel radio.
- Existing game theoretical solutions are not finding upper and lower limits of the performance under saturated and un-saturated traffic conditions.
- Existing game theoretical models are based on full information which is far from real-world scenario. In real-world wireless network scenario, many parameters are unknown so game theoretical solution should be proposed with incomplete information.
- In many cases achieving global optimization is an NP-hard problem so the best solution is to find sub-optimum solution with pareto-efficiency. However, many existing solutions have not shown the same.

In this work the focus of our research is to optimize the network performance using game theoretical framework at the MAC layer. The goal of this paper is to minimize energy usage in the game-based MAC protocol on the basis of the literature survey and the established constraints of current work to the best of our knowledge. This paper proposes a sleeping system to significantly maximize energy efficiency. Based on identified gaps, this paper is contributing as follows.

- Propose the sleeping mechanism for game based MAC protocol.
- Detailed analysis on energy-efficiency of the game based MAC.
- Detailed numerical analysis and comparison of game based MAC protocol with and without sleep mechanism.
- With numerical results it is projected that game-based MAC protocol has improved energy efficiency of overall network by 85% to 95%.

The rest of the paper is organized as follows. In Section 1 the related work is presented. Later, in Section 2 the proposed scheme with numerical analysis is presented. Then, Section 3 focuses on numerical results obtained from performed analysis. Finally, concluding remark is given in Section 4.

2. Proposed Sleeping Mechanism.

The paper suggests a method of allocating control during backoff algorithm execution by eliminating uninterrupted listening. The suggested scheme is a hybrid solution that gains from CSMA/CA schemes of IEEE 802.11 and IEEE 802.15.4. This scheme would not use any extra signalling medium or an overhead in the protocol concerned. Numerical analysis shows that the proposed scheme reduces the energy consumption significantly over traditional backoff algorithm.

2.1. Sleep mechanism for backoff algorithm.

BEB is using a p-persistent backoff CSMA/CA MAC protocol. The IEEE 802.11/802.22 BEB work was outlined in [2,4]. During the time of the contention, a node spends most of its time listening to the channel. The node selects the backoff interval in a BEB mechanism, $[CW_{\min} \ldots CW_{\max}]$, where $CW_{\min}$ and $CW_{\max}$ are the lowest and highest values respectively. A sleep system to save power usage during idle listening is suggested in this article. Figure 3 shows the working of the proposed mechanism. Figure 4 shows a typical time division multiple access (TDMA) mechanism. TDMA nodes are synchronized with each other and assigned with dedicated slots for communication. During the non-assigned slots a node can put the radio in sleep mode to minimize the energy consumption. TDMA is easy to implement in centralized networks, as shown in Figure 1, as there is a central entity to assign dedicated slot(s) to nodes and synchronize the network. In distributed networks synchronization is hard to

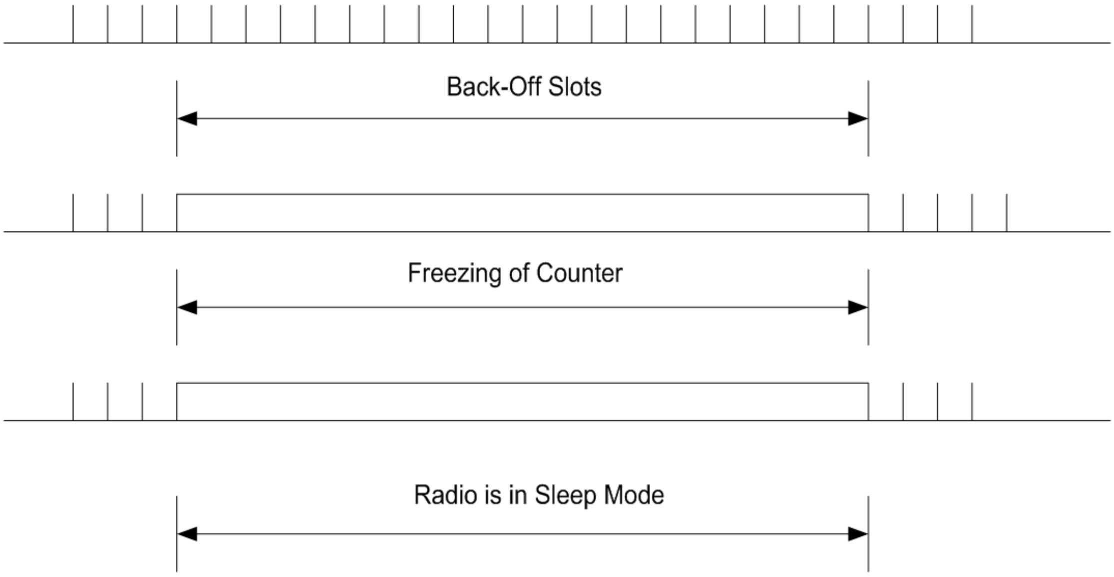

Figure 3. Sleeping mechanism of BEB

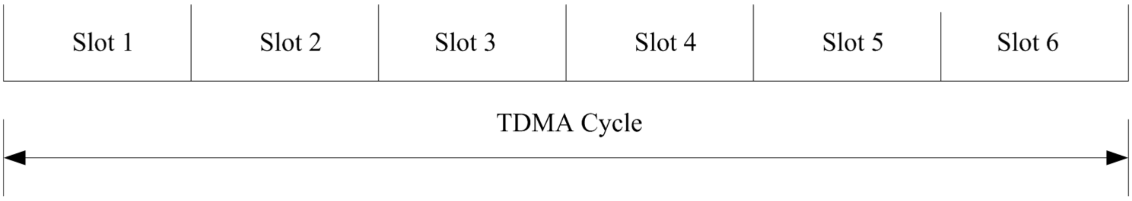

Figure 4. A typical TDMA cycle

achieve or loose synchronization may be achieved. As shown in Figure 3 BEB runs on small slotted backoff slots. A node senses the channel or listens to the channel during that time. Whenever a node listens to any ongoing transmission or busy channel, it goes for freezing mode for pre-defined time. A node may put itself into sleeping mode for saving the energy. Moreover, when a node is decrementing CW, it can go in sleep mode for pre-selected CW count.

A node chooses the contention window as per the normal working of BEB, if CW is larger than threshold value ($\boldsymbol{\tau}_E$), the new CW is calculated and CW is set to 2 ($CW = 2$ is good duration to consider any ongoing transmission). If CW is less than $\boldsymbol{\tau}_E$, then the value of CW is initialized with its original value. Threshold value is defined as presented in equation no 7. Based on working of BEB [2], there are four cases of working as follows.

Table 1. Four cases of CW

Cases	Channel condition	CW value =	Node	Status of CW
1	Busy	$2-1=1$	Senses the channel	Is freeze, sets for next backoff period
2	Idle	$2-1=1$	Senses the channel	Is decremented
3	Busy	$1-1=0$	Senses the channel	Is freeze and set for next back off period
4	Idle	$1-1=0$	Attempts to transmit	Selects new CW value

2.2. **System model.** Now to analyze the proposed mechanism, numerical model presented in [2] is adopted. In the presented numerical analysis, we have used following mathematical notations as summarized in Table 2.

Table 2. Mathematical notations

Symbol	Meaning	Symbol	Meaning
MD	Medium access delay	E_{Succ}	Consumption of energy in efficient transmission
$E[MD]$	Average MD	E_{Coll}	Consumption of energy for collided transmission
$E[N_{coll}]$	Average number of collisions of a frame before its successful reception	η_e	Energy efficiency
$E[B_{del}]$	Average back off delay	P_{tx}	Transmitting power
L	Length of data packet in bit	P_{rx}	Being idle and listening power
$E[X_{avg}]$	Average back off value	p_s	Probability of success
$E[N_{Fr}]$	Average number of times a node freezes its counter before it reaches state θ.	S	Successful number of packets
$E[\alpha]$	Mean number of sequential idle slots	P_{pro}	Propagation delay
E_{Total}	Total energy consumption for transmission of a data packet	CW_0	Minimum contention window
E_{Back}	Back-off stage energy consumption	$\boldsymbol{\tau}_E$	Threshold value
E_{List}	Energy consumption in overhearing	E_{SL}	Transition energy from sleep to hearing

2.3. **Energy model.** As energy efficiency is an important metric to compare the effectiveness of any protocol. Therefore, it is necessary to present the energy model. As preference model presented in [2], the total energy consumption to transmit a data packet is given by

$$E_{Total} = E_{Back} + E_{List} + E_{Succ} + E_{Coll} \tag{1}$$

Now, the energy efficiency is given by

$$\eta_e = \frac{E_{Total}}{L} \tag{2}$$

The total energy consumption in back off, E_{Back}, is given by

$$E_{Back} = E[X_{avg}] \times E[N_{coll}] \times S \times P_{rx} \tag{3}$$

The listening energy consumption E_{List} is given by

$$E_{List} = E[N_{coll}] \times E[X_{avg}] \times S \times P_{rx} \tag{4}$$

Here, E_{Succ} is the consumption of energy for efficient transmission and is

$$E_{Succ} = (H_{P+M} + T_{Data/Req}) \times P_{tx} + (T_{SIFS} + P_{pro} + T_{ACK} + P_{pro} + T_{DIFS}) \times P_{rx} \tag{5}$$

Similarly, the E_{Coll} is the energy consumption for collision and given by

$$E_{Coll} = (H_{P+M} + T_{Data/Req}) \times P_{tx} \times E[N_{coll}] + (T_{SIFS} + P_{pro} + T_{DIFS}) \times P_{rx} \times E[N_{coll}] \tag{6}$$

The mathematical equations presented above indicate that reasonable amount of energy is lost in idle listening in back off stage and listening. To reduce the waste component, sleep mechanism is introduced. In sleep mechanism, the radio will switch from ON to SLEEP and SLEEP to ON. These transitions also consume some energy. Therefore, it is required to make sure that node will go to sleep mode only when contention window value is more than threshold value (energy consumes more than transition energy).

$$\boldsymbol{\tau}_E = 2E_{SL} + 4E_{List} \times S \tag{7}$$

where E_{SL} means the node requires energy to shift from listening to sleep to hearing. E_{List} as shown in Equation (4) is redefined as follows

$$E_{List} = E[N_{coll}] \times E[X_{avg}] \times S \tag{8}$$

$$E[X_{avg}] = \frac{(CW_0 - 1)}{2} \tag{9}$$

$$E[N_{coll}] = \frac{1}{p_s} - 1 \tag{10}$$

3. Results and Discussion.

Numerical analysis to validate the system model is provided in this section. MATLAB tool is used to implement the system model with assumed parameters based on [2]. These parameters are as follows. Data packet size is considered from 128 to 1024 Bytes with a 12 Bytes MAC header and 10 Bytes of physical header and Acknowledgement. The receiving/idle listening and transmitting energy is 1 and 1.5 units respectively. Here, three strategies have been considered as defined in [2], small (0-127), medium (0-511), and large (0-1023). The network density from high to low has been depicted by varying the number of nodes surrounded by source node. Nodes 5 and 25 are indicating low and high densities of network, respectively.

In this section, the comparison of two scenarios as without and with sleeping mechanism has been considered. Without sleeping mechanism scenario basically represents the category of MAC protocol based on 802.11, whereas sleep mechanism scenario presents the category of MAC protocols with sleep mechanism. Numerical results shown in Tables 3, 4 and 5 are obtained using the system model presented in Section 2. All required parameters are set as per [2]. In this section, impact analysis of sleeping mechanism is considered with the two mentioned scenarios. It is worth noting that sleeping mechanism

Table 3. Small strategy

Sr. No.	No. of slots	Listening energy (with sleep mechanism) (μj)	Listening energy (without sleep mechanism) (μj)	Energy efficiency
1	1	0.01	0.5	98%
2	20	2.1	105	
3	40	8.2	410	
4	60	18.3	915	
5	80	32.4	1620	
6	100	50.5	2525	
7	120	72.6	3630	

Table 4. Medium strategy

Sr. No.	No. of slots	Listening energy (with sleep mechanism) (μj)	Listening energy (without sleep mechanism) (μj)	Energy efficiency
1	1	0.01	0.5	98%
2	50	13.26	663	
3	100	50.5	2576	
4	150	114.8	5588	
5	200	201	10050	
6	250	318.8	15813	
7	300	451.5	23028	

Table 5. Large strategy

Sr. No.	No. of slots	Listening energy (with sleep mechanism) (μj)	Listening energy (without sleep mechanism) (μj)	Energy efficiency
1	1	0.01	0.5	98%
2	200	201	15813	
3	400	806.01	40100	
4	600	1809.01	93483	
5	800	3204	161403	
6	1000	5105.6	251753	
7	1023	5237.8	262400	

is useful only when CW is greater than $\boldsymbol{\tau}_E$ value. $\boldsymbol{\tau}_E$ value is set to $CW = 4$, based on numerical analysis. This is also indicated in following plots, at the lower value of CW, there is no gain in energy efficiency. Based on numerical analysis, results are depicted in Figures 5, 6 and 7 with respective numerical values presented in Tables 3, 4 and 5.

In Tables 3, 4 and 5 the comparison of two scenarios as without sleeping mechanism and with sleeping mechanism has been done. The threshold value is calculated, if CW is more than the threshold value $\boldsymbol{\tau}_E$ then use Equations (7) and (8) with various slot values and consider different system model parameters as shown in Table 1.

Figure 5 shows the average energy consumption during the two scenarios. Here small strategy means $CW = $ [0-127]. As shown in Figure 5, there is big gain in energy efficiency. Figure 6 shows the medium consumption of energy ($CW = $ [0-511]). If the strategy is medium likewise, Figure 7 indicates the typical high-strategy energy consumption ($CW = $ [0-1023]).

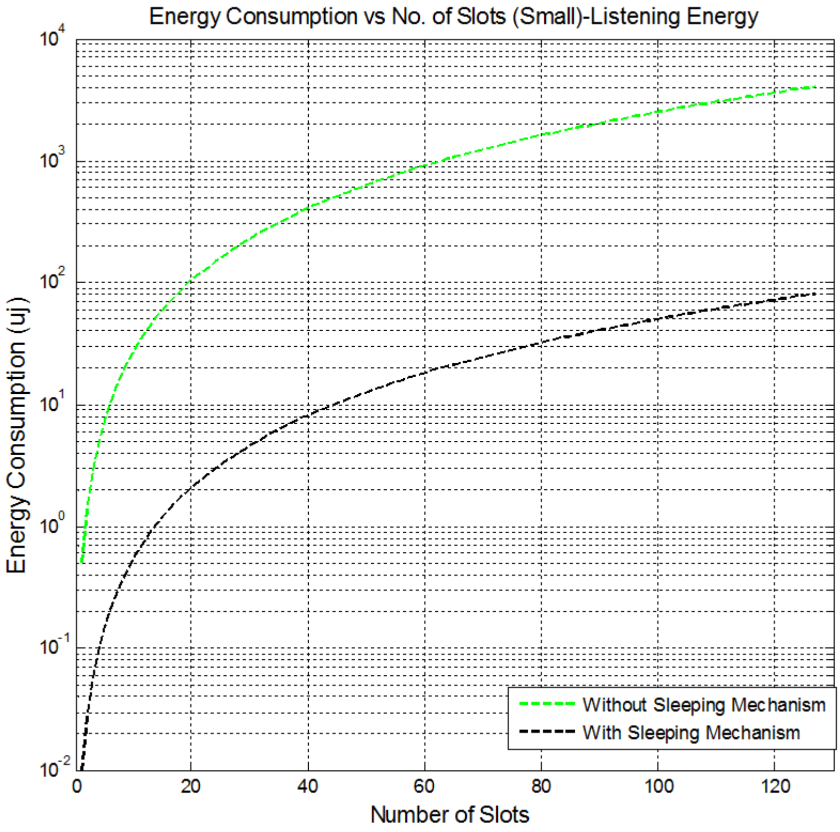

Figure 5. Variation of average energy consumption with number of slots (small)

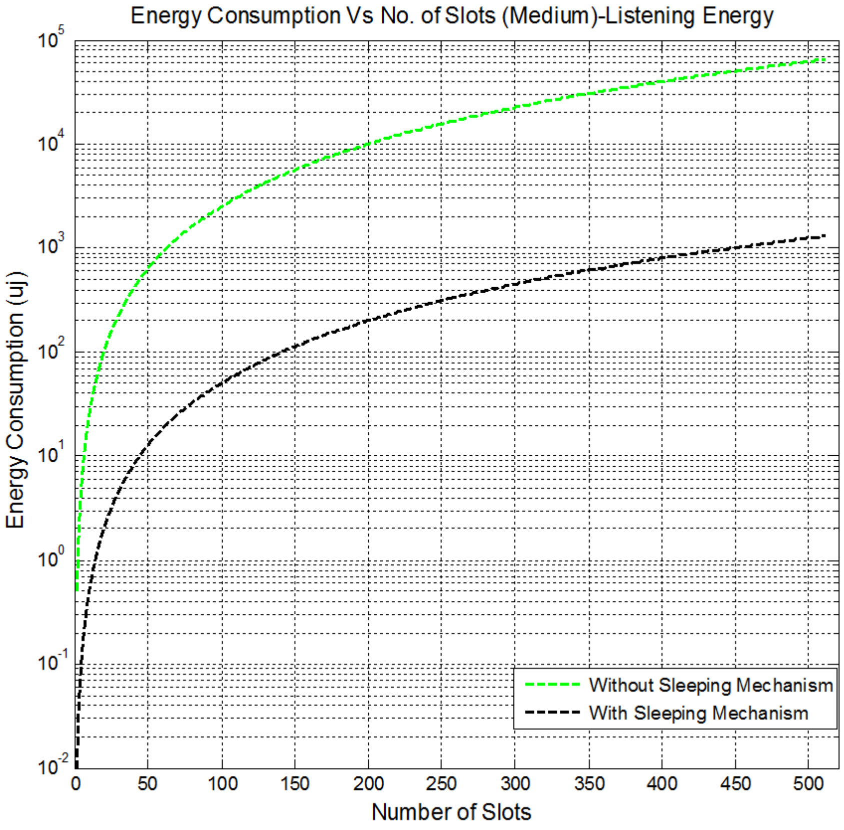

Figure 6. Variation of average energy consumption with number of slots (medium)

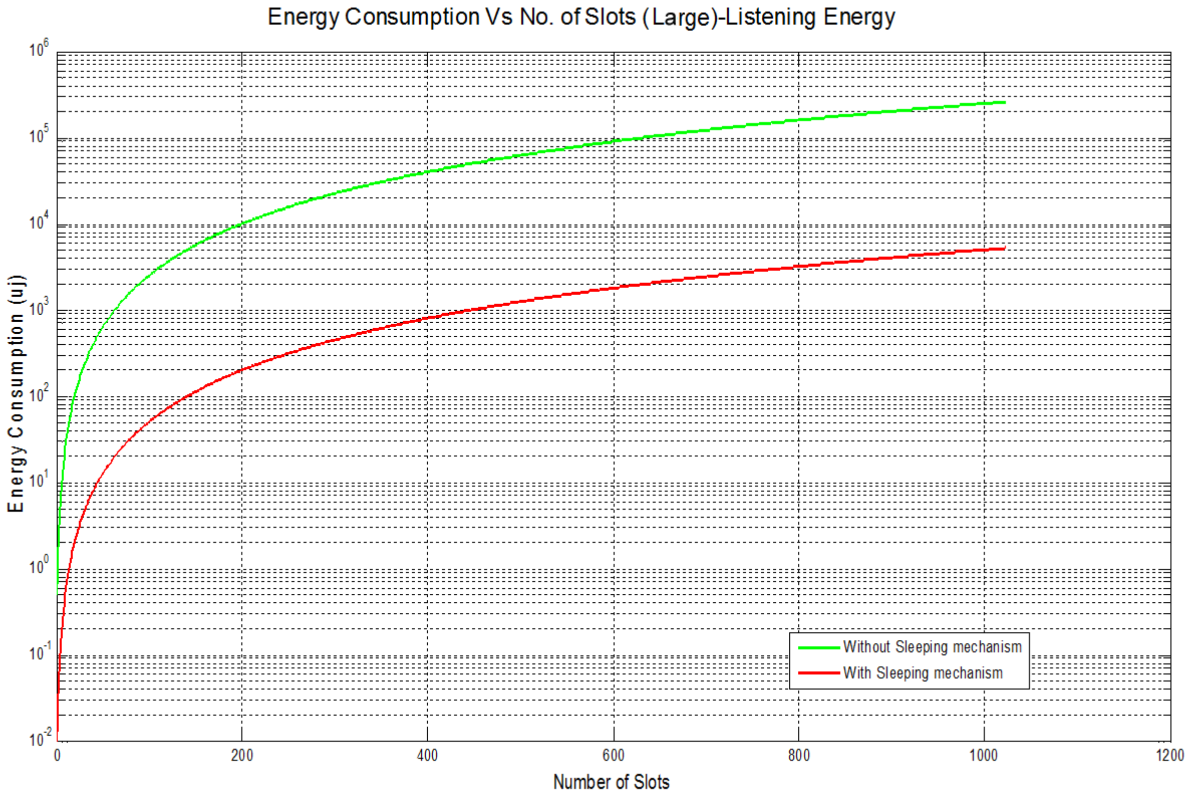

Figure 7. Variation of average energy consumption with numbers of slots (large)

Table 6. Strategy and numbers of nodes

Strategy	Number of neighbouring nodes (density of nodes)			
	5	10	20	25
Small	85%-95% gain			
Medium				
Large				

From Figures 5, 6 and 7[1], it is observed that in each case 98% of the energy efficiency is achieved as putting radio in sleep mode saves lots of unnecessary wastage of energy. As these results are based on numerical model, few parameters are assumed as per [2] and simplified conditions (such as avoiding noise, no capturing effect, transition energy from one state to another, and variable range), so there might be some chance of error. Therefore, keeping error margin (of 13%-15% as range) in view, one could achieve 85%-95% energy efficiency in different strategies with different densities as presented in Table 6. This gain is obtained from the aforementioned Figures 5-7. It is important to note that all energy efficiency is almost independent of strategy and density of the nodes. As game-MAC, presented in [2], taking care for collision there is no energy waste or minimum energy waste in re-transmission and no effect of density of the nodes as well. Due to space limitation, detailed readings are not given but efficiency percentage is calculated on the average values.

4. **Conclusions.** As discussed in the paper, it is possible to reduce the energy consumption further by introducing sleeping mechanism during the contention window counter (CC) decrement to achieve the energy efficiency. In the proposed solution, a node selects the contention window (CW) size as per the selected strategy. Later, a node will try to

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[1] As Figures 5, 6, and 7 are presenting the same understanding with different window intervals deduction of learning is the same and applicable to all of them.

attend the transmission once the contention window counter (CC) reaches zero. However, during the contention window counter (CC) decrement, a node unnecessarily listens to channel and consumes energy. Using this mechanism node can go to sleep mode during the back-off counting, so node can save unnecessary energy in idle/overhearing listening. This mechanism does not interfere with existing MAC protocol and could be adopted with any IEEE 802.11 based BEB algorithm. The proposed solution has been tested with numerical analysis and supports our intuitions. Obtained results show that sleeping mechanism can improve the energy efficiency by 85%-95%. As presented here, all nodes have three basic strategies: small, medium, and large. These strategies are based on different contention window sizes such as small (0-127), medium (0-511), and large (0-1023). With these different strategies, it will be interesting to know how many strategies are required, what should be the ideal interval of a strategy, etc., in our future work.

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