SIMULATION AND EVALUATION ABOUT MAC PROTOCOLS IN WIRELESS SENSOR NETWORK USING NS2

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Abstract:

One of the major challenges of wireless sensor networks (WSN) is how to utilize efficiently battery energy resource to extend the lifetime of the entire network because of power constrained devices. Many MAC (Medium Access Control) protocols have been taken to decrease the energy consumption of sensor nodes such as IEEE 802.11, 802.15.4 MAC or sensor MAC (S-MAC) protocols. In this paper, we provide analyses performance of IEEE 802.11, 802.15.4 MAC and S-MAC protocols in terms of throughput, energy consumption and data packet delivery. Our simulation results show that S-MAC protocol with active and sleep cycle consumes energy less than about 10% and 15% compared to IEEE 802.15.4 and IEEE 802.11 MAC protocols respectively.

Keywords: *Wireless Sensor Networks, energy-efficient, S-MAC, IEEE 802.15.4, IEEE 802.11.*

I. Introduction

Wireless sensor network (WSN) includes hundreds or thousands of micro-sensor nodes which is deployed in various fields such as military, environment monitor, intelligent home and so on [11]. Sensor nodes have a small size low cost, processor abilities, RAM and resources. Especially, the battery power of node is not recharged during the active time of network. Therefore, it is very important for considering energy consumption of MAC protocols in order to save energy and prolongs the lifetime of network. MAC protocols are designed at MAC sub layer in data link layer in OSI model, which is responsible for controlling medium access so that the nodes in network can communicate with other nodes available without occurring collision. Besides, the energy efficient also is one of utmost importance for designing MAC protocols in order to extend the life of the network as long as possible.

In WSN, a sensor node consumes energy in idle listening of the channel, transmission, reception, sleep state or transition state, in which idle listening is one of the most significant sources of energy consumption in sensor nodes. In order to limit the problem of idle listening, currently, many MAC protocols has proposed by researchers for this problem as well as evaluated about energy efficient of that, such as IEEE 802.11, IEEE 802.15.4 MAC protocol or Sensor-MAC (S-MAC) protocol [1, 4, 5, 8, 9].

Bengheni [1] et al. compares energy consumption of asynchronous MAC protocols in wireless sensor networks: BMAC, XMAC and RIMAC that use a duty-cycle to reduce idle listening, which is cause of waste energy.

In [2, 9] the authors have analyzed the performance of S-MAC, which operate at different duty cycles and estimate the parameters required to achieve any desired throughput, data rate and energy consumption.

Recently, Kobayashi [4] et al. proposed a method energy saving by combining the IEEE 802.11with IEEE 802.15.4. If the big data packets is are sent, the method will use IEEE 802.11 for high throughput. On the other hand, if the size of data packet is small, IEEE 802.15.4 is selected to decrease energy consumption. Up until now, there have been many analysis and evaluation of energy efficient MAC Protocols in WSN such as simulation and performance evaluation of energy efficient MAC Protocols [3], simulation and analysis of energy consumption for S-MAC and T-MAC protocols [8], energy consumption in mobile ad hoc networks [5]. However, none of the above evaluations consider the energy efficient between S-MAC and the IEEE 802.11, 802.15.4 MAC protocols.

In this paper, we focus on the performance evaluation of the S-MAC and IEEE 802.11, 802.15.4 MAC protocols to help the development of power saving schemes in WSN. Our simulation results show that the energy consumption of S-MAC with active and sleep cycle consumes energy less than about 10% and 15% compared to IEEE 802.15.4 and IEEE 802.11 MAC protocols, respectively, in case of large network (50 nodes deployed in 500m×500m area). Besides the energy consumption of idle listening state is the most in comparison with transmission and reception state in all protocols.

II. Protocols Description

In this section, we briefly describe the IEEE 802.11, IEEE 802.15.4 MAC and S-MAC protocols, which are used in our analysis.

A. IEEE 802.11

Standard IEEE 802.11 is a contention based MAC protocol for controlling medium access in wireless local area network (WLAN) [11]. IEEE 802.11 can work at two modes: the distributed coordination function (DCF) and the point coordination function (PCF) mode. In the PCF mode, nodes communicate with each other through a central device called access point (AP) or base station (BS) to manage medium environment access of all nodes, thus it can avoid packet collisions. In the DCF mode, nodes communicate directly with each other based on CSMA/CA algorithm, that is, before a node transmits a packets to the medium, it first call clear channel assessment (CCA) procedure to sense the medium for activity. If the medium is idle for at least a inter-frame space time (DIFS), the node can transmit packets. Otherwise, the node runs a back-off algorithm to delay transmission to a later time. The binary exponential back-off algorithm will randomly select a number of time slots to wait and store this value for a back-off counter for later time.

IEEE 802.11 was designed for one hop links in network; it provides efficiently services networks due to its basic characteristics as high bit rates, simple to implement, flexibility in architecture and a cost effective method for channel allocation, but due to the fact that it is not sleep period strategy and consumes more energy in long idle listening, thus it is not suitable for WSN.

B. IEEE 802.15.4

IEEE 802.15.4 standard is designed for low-rate and low-power applications [11]. In physical layer, it can work at three operational frequency bands: 868 MHz, 915 MHz, and 2.4 GHz bands. There are 27 sub-channels defined in IEEE 802.15.4 standard, which consists of 16 sub-channels in 2.4 GHz band, 10 sub-channels in 915 MHz band and one sub-channel in the 868 MHz band. IEEE 802.15.4 standard can operate in two modes: a beacon-enabled mode and non-beacon enabled mode. In a non-beacon enabled mode, IEEE 802.15.4 uses un-slotted CSMA/CA algorithm to control medium access and maintain network activities. In a beacon-enabled mode, the network is managed by a coordinator device, which regularly transmits a beacon frame to other devices to synchronize and identify network. The beacon-enabled mode of IEEE 802.15.4 consists of a contention access period (CAP), a contention free period (CFP) and inactive period that is in a super-frame. The super-frame structure is shown as Figure 1 follows:

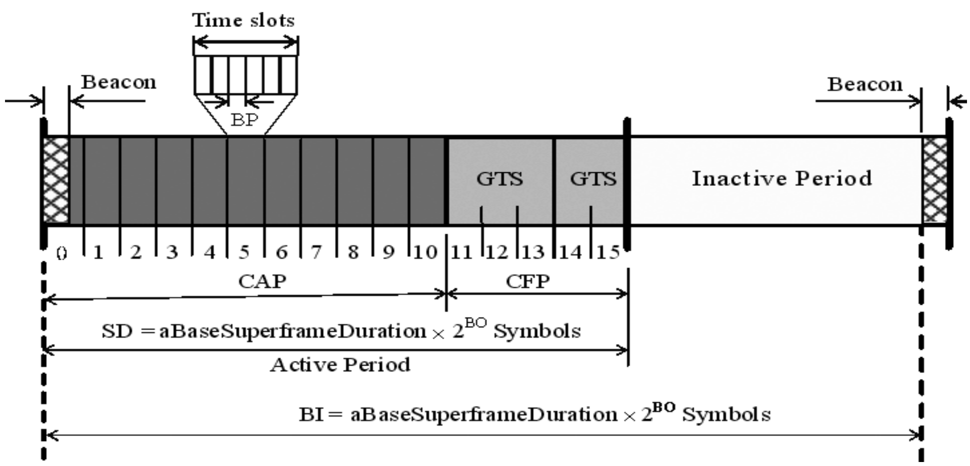

Fig. 1. *Superframe structure of IEEE 802.15.4*

where aBaseSuperframeDuration = 960 symbols, 1 symbol = 16 µs, BO is Beacon Order, and SO is Superframe Order. The coordinator communicates with other nodes during the active period and sleeps during the inactive period. In a beacon-enabled mode, the nodes use a slotted CSMA/CA protocol in the CAP period to transmit data packets to other nodes. To save energy, all the nodes will go into a sleep period during the long inactive period.

C. Sensor-MAC (S-MAC)

S-MAC [2, 7] is a medium access control protocol base on contention-based random access that allows nodes directly communicate to each other in network. S-MAC is designed to reduce energy consumption from all the sources for wireless sensor networks that we can identify to cause energy waste (collision, idle listening, overhearing and control overhead) by using fixed listen and sleep duty cycle called a time frame, in which nodes periodically transition between a listen state and a sleep state to reduce energy consumption in idle listening channel.

A time frame in S-MAC contains two parts: one for a listening period and the other for a sleeping period as shown in Figure 2 follow:

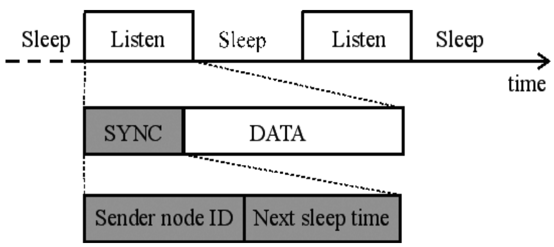

Fig. 2. *Listen and sleep period of S-MAC*

During a listen period, the nodes communicate with other nodes by exchanging SYNC, Request-To-Send (RTS), and Clear-To-Send (CTS) messages before transmitting data packets. In sleep period, the nodes will turn off radio fully to save energy and wake up at a scheduled time in a next frame. If a node has data to send in this period, it must defer its transmission until the next listen period.

In order to synchronize the time of listen and sleep period among nodes in network, the nodes regularly share their information about schedule table by broadcasting SYNC message, which is very small and consist of node ID (identification), the next sleep time...

In network, a packet collision occurs when two or more nodes attempt to transmit packets into the medium over the network at the same time. Packet collisions can be the cause of wasting energy and decreasing performance network. To solve this problem, S-MAC uses traditional mechanisms like the IEEE 802.11 such as the exchange of RTS/CTS message and using ACK message to affirm a good data packet received. In addition, S-MAC combines the physical carrier sensing called Clear Channel Assessment (CCA) and virtual carrier sensing called Network Allocation Vector (NAV) to avoid collision and overhearing. NAV contains a value, only when this value is set to zero, packets can be transmitted.

D. Simulation Parameters

To evaluate the performance of IEEE 802.11, 802.15.4 MAC and S-MAC protocols, we use the network simulator ns-2 (v.2.35) [10] with the parameters in the scenarios that are described in Table I, [6, 7, 12].

Table I. *The Arrangement of Channels*

Parameters	Values
Topology area	500 m × 500 m
Numbers of nodes	50
Antenna type	Omni Antenna
Routing protocol	AODV
Packet size	128 bytes
Simulation time	500 seconds
Transmission range (m)	250
Traffic type	CBR
Data rate	1 (kbps)
Initial energy	2 (Joules)
Idle power	712e-6 (Watt)
Receiving power	0.3 (Watt)
Transmission power	0.6 (Watt)
Sleep power	144e-9 (Watt)

E. Performance Metrics

1) Energy Consumption

Energy consumption denotes the relationship among energy dissipation to the total of data packets delivered by each node in the network. A node consists of energy consumption in different states as transmission (E_{Tx}), reception (E_{Rx}), idle listening (E_{Idle}), sleeping (E_{Slep}), transition (E_{trans}) and CCA (E_{CCA}) state that can be calculated as follows:

$$E_{node} = E_{Tx} + E_{Rx} + E_{Idle} + E_{Sleep} + E_{Trans} + E_{CCA}$$
$$= \sum_{i=1}^{Ntx} P_{Tx} Ps_i / R + \sum_{j=1}^{Nrx} P_{Rx} Ps_j / R + P_{Idle} T_{Idle} + P_{Sleep} T_{Sleep}$$
$$+ \sum_{k=1}^{N_{trans}} P_{trans} T_{trans}(k) + P_{CCA} T_{CCA} \quad (1)$$

where E_x, P_x and T_x are the energy consumption (joules), the power (watt) and the time interval of transceiver in state x (second). Ps_i and R are the size of length of the i[th] packet of receiving or sending and R is the data transferring rate. N_{tx} and N_{rx} are total numbers of receiving or sending packets.

$$E_{AN} = \frac{\sum_{i=1}^{n} E_{node}(i)}{n} \quad (2)$$

where E_{AN} are the average energy consumption of all nodes in network, n is number of nodes in network.

2) Throughput:

Throughput express the total count of data packets transported to destination nodes of one flow (connection) in network during the simulation time.

The average throughput of the entire network expresses the average throughput of each connection. The average throughput of each connection is calculated by the total size of received packets at destination node per the time, which takes for traffic to flow through the connection.

$$\text{Throughput\_of\_ flow}_j = \frac{\sum_{i=1}^{m} Ps_i * 8}{t_2 - t_1} \quad (bps) \quad (3)$$

$$\text{Throughput\_of\_ network} = \sum_{j=1}^{k} (\text{Throughput\_of\_ flow})_j \quad (4)$$

where Ps_i is the size of length of the i[th] packet reaching the destination, t_1 and t_2 are the time when first packet sent by source node and the time when last packets received by destination node, respectively.

3) Energy Efficiency:

Energy efficiency is defined as the throughput achieved per unit of energy consumed, where the throughput represents the number of successfully delivered packets.

$$\text{Energy\_efficiency} = \frac{\text{Throughput(packets)}}{\text{Energy\_consumption(Joules)}} \quad (5)$$

4) Packet Delivery Ratio (PDR):

PDR represents the ratio of data packets successfully received from all the sent data packets, which is computed as below:

$$PDR = \frac{Nr}{Ns} \quad (6)$$

Where Nr and Ns are the number of packets received by destination node and the number of packet sent by source node, respectively.

III. Results and Analysis

Figure 3 represents the percentage of power consumption of IEEE 802.15.4, 802.11 MAC and S-MAC protocols during simulation time. It is clearly observable that the S-MAC protocol with active and sleep cycle has better performance in reducing energy consumption of nodes than IEEE 802.15.4 and 802.11 MAC protocols.

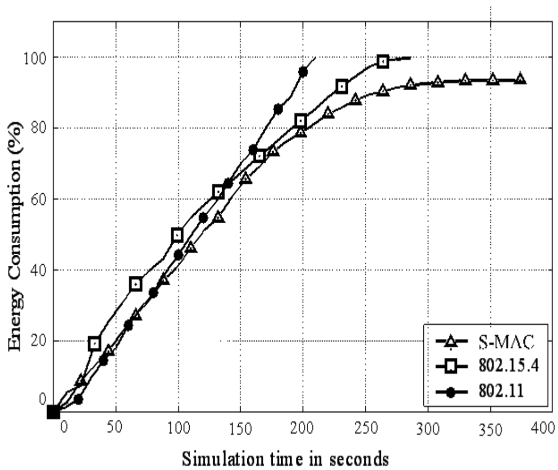

Fig. 3. *Energy consumption during the simulation time*

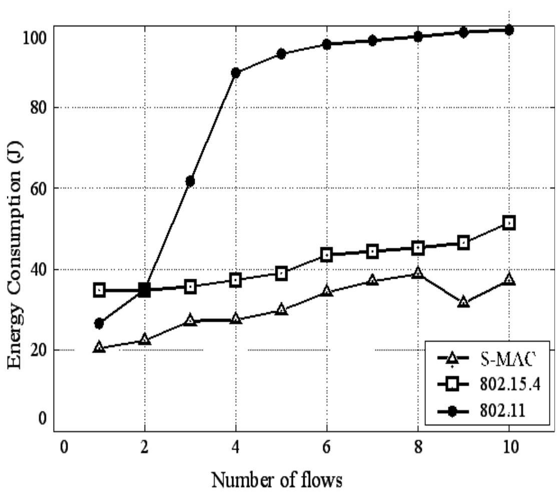

Fig. 4. *Energy consumption per number of flows*

Figure 4 shows the energy consumption of nodes when we increase the number of connection (flow) in network. It seems that energy consumed increases as the number of nodes sent data packets increases with all MAC protocols, but it is rapid increase about energy consumption with IEEE 802.11 MAC and S-MAC having the lowest consumption of energy.

As illustrated in Figure 5 and 6, the average throughput and energy efficiency of protocols is analyzed in increased number of sent nodes. We can see that IEEE 802.11 MAC with the high throughput achieved the better energy efficiency than IEEE 802.15.4 MAC and S-MAC protocols.

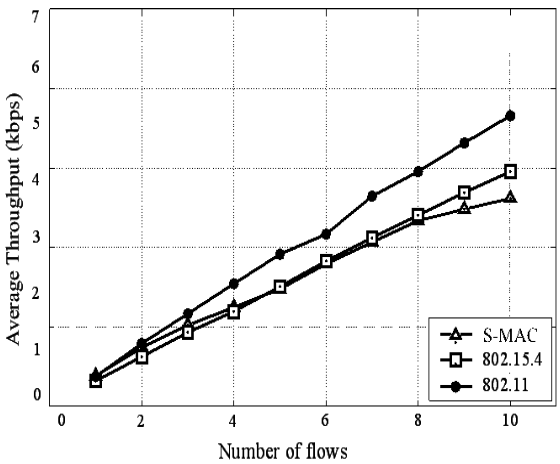

Fig. 5. *The average throughput*

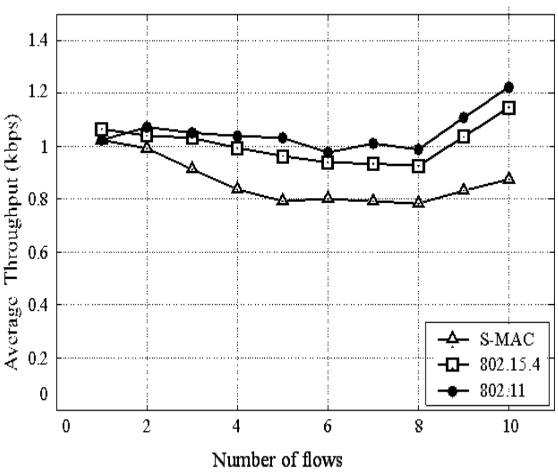

Fig. 6. *Energy efficiency*

In Figure 7, we illustrate the packet delivery ratio for both three protocols in the number of flows. Based on results shown in Figure 6, we can obviously observe that the packet delivery ratio in the network in the IEEE 802.11 MAC protocol is higher than about 200% compared to IEEE 802.15.4 MAC and S-MAC protocols.

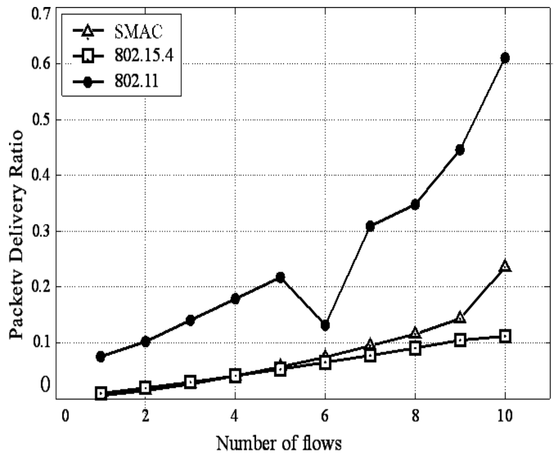

Fig. 7. *Packet delivery ratio*

The percentage of energy consumption in different states of all nodes in network are illustrated in Figures 8, 9 and 10 in which idle listening state consumes more energy than other states, it is 87.7%, 59 and 59% with IEEE 802.11, % IEEE 802.15.4 MAC and S-MAC, respectively. The sleeping and transition state consume lowest energy but the total of energy consumption of IEEE 802.11 and 802.15.4 MAC protocols are still more higher than S-MAC because nodes have listened channel to check packets came while S-MAC achieves energy efficiency by switching the radio in sleep and active state periodically, so S-MAC achieves energy savings thereby providing longer lifetime of network.

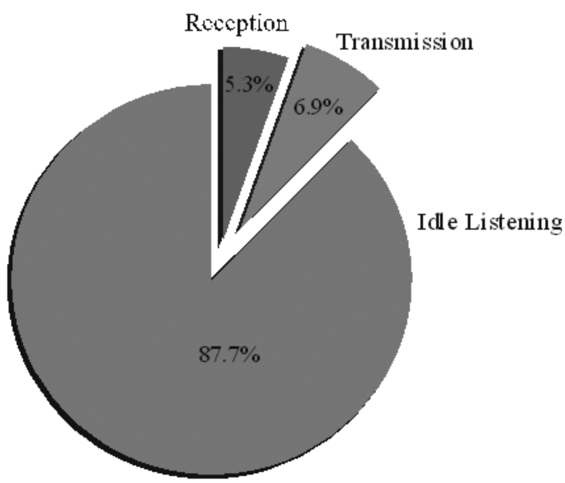

Fig. 8. *Energy consumption in several states with IEEE 802.11 MAC*

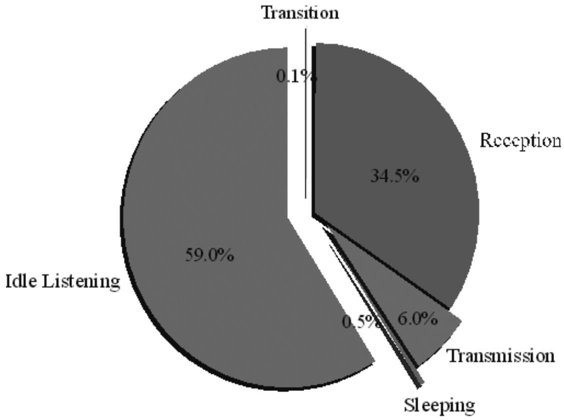

Fig. 9. *Energy consumption in several states with S-MAC*

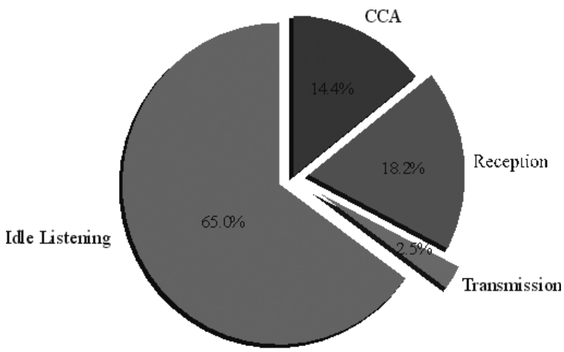

Fig. 10. *Energy consumption in several states with IEEE 802.15.4 MAC*

IV. Conclusion

In this paper, we analyzed the energy consumption of nodes in wireless sensor network considering the interactions of the IEEE 802.11, 802.15.4 MAC and S-MAC protocols. Our goal is to evaluate performance of MAC protocols which helps the development of power saving schemes in WSN. Our simulation results show that the energy consumption of S-MAC with active and sleep cycle is better than that of IEEE 802.15.4 and IEEE 802.11 MAC protocols about 10% case of large network (50 nodes deployed in 500m×500m area). Besides IEEE 802.11 consumes more energy but it has the packet delivery ratio is the most in MAC protocols.

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MÔ PHỎNG VÀ ĐÁNH GIÁ CÁC GIAO THỨC TRUY NHẬP MÔI TRƯỜNG TRUYỀN TRONG MẠNG CẢM BIẾN KHÔNG DÂY SỬ DỤNG NS2

Tóm tắt:

Một trong những thách thức của mạng cảm biến không dây là làm sao sử dụng hiệu quả nguồn năng lượng pin quý hiếm nhằm kéo dài thời gian sống của toàn bộ mạng vì các nút mạng sau khi sử dụng hết nguồn pin, chúng sẽ chết. Nhiều giao thức điều khiển truy cập môi trường truyền đã được đề xuất nhằm giảm năng lượng tiêu thụ của các nút cảm biến như chuẩn IEEE 802.11, 802.15.4 và giao thức S-MAC. Trong bài báo này, chúng tôi cung cấp đánh giá quá trình tiêu thụ năng lượng, thông lượng và sự chuyển phát gói tin của chuẩn IEEE 802.11, 802.15.4 và giao thức S-MAC. Các kết quả mô phỏng của chúng tôi cho biết rằng giao thức S-MAC với các chu kỳ hoạt động - ngủ tiêu thụ năng lượng ít hơn khoảng 10% khi so sánh với chuẩn IEEE 802.15.4 và ít hơn khoảng 15% khi so sánh với chuẩn IEEE 802.11.

Từ khóa: *Mạng cảm biến không dây, hiệu quả năng lượng, S-MAC, IEEE 802.15.4, IEEE 802.11.*