Minimizing the Energy Consumption in Wireless Sensor Networks

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Abstract

Energy in Wireless Sensor networks (WSNs) represents an essential factor in designing, controlling and operating the sensor networks. Minimizing the consumed energy in WSNs application is a crucial issue for the network effectiveness and efficiency in terms of lifetime, cost and operation. Number of algorithms and protocols were proposed and implemented to decrease the energy consumption. WSNs operate with battery powered sensors. Sensors batteries have not easily rechargeable even though having restricted power. Frequently the network failure occurs due to the sensors energy insufficiency.

MAC protocols in WSNs achieved low duty-cycle by employing periodic sleep and wakeup. Predictive Wakeup MAC (PW-MAC) protocol was made use of the asynchronous duty cycling. It reduces the consumption of the node energy by allowing the senders to predict the receiver′s wakeup times.

The WSN must be applied in an efficient manner to utilize the sensor nodes and their energy to ensure efficient network throughput. Prediction of the WSN lifetime previously to its installation represents a significant concern. To ensure energy efficiency the sensors duty cycles must be adjusted appropriately to meet the network traffic demands. The energy consumed in each node due to its switching between the active and the idle states were also estimated. The sensors are assumed to be randomly deployed.

This paper aims to improve the randomly deployed network lifetime by scheduling the effects of transmission, reception and sleep states on the sensor node energy consumption. Results for these states with many performance metrics were also studied and discussed.

Keywords: WSN, Energy Consumption, PW-MAC, Duty Cycling, sleep, wakeup, Simulation.

الخلاصة

تمثل الطاقة في شبكات الاستشعار اللاسلكية عاملاً اساسياً في تصميم ومراقبة وتشغيل هذه الشبكات. تعد عملية التقليل من الطاقة المستهلكة في شبكات الاستشعار اللاسلكية وتطبيقاتها مسألة حيوية بالنسبة لفعالية وكفاءة الشبكة من حيث العمر والتكلفة والتشغيل. تم اقتراح وتنفيذ العديد من الخوارزميات والبروتوكولات لتقليل استهلاك الطاقة. شبكات الاستشعار اللاسلكية تعتمد على اجهزة الاستشعارتعمل ببطارية. بطاريات اجهزة الاستشعار لايمكن اعادة شحنها بسهولة على الرغم من طاقتها محدودة. كثيراً مايحدث الفشل في الشبكة نتيجة عدم كفاية طاقة اجهزة الاستشعار. حققت بروتوكولات مراقبة الدخول المتوسط (MAC) في شبكات الاستشعار اللاسلكية انخفاض في دورة اشتغاله من خلال توظيف مبدا النوم (السكون) والاستيقاض الدوري. حقق بروتوكول مراقبة الدخول المتوسط ذات الاستيقاظ التنبؤئ استفادة من مبدأ دورة الاشتغال غير المتزامن.

يقلل هذا البروتوكول من استهلاك العقدة للطاقة من خلال السماح للمرسلين بالتنبؤ باوقات استيقاظ المستقبلين. يجب تطبيق شبكة الاستشعار اللاسكلية بطريقة فعالة لتوظيف عقد الاستشعار وطاقتها لضمان انتاجية شبكة كفوءة. ان التنبؤ بعمر شبكة الاستشعار اللاسلكية قبل بناءها يمثل اهتماما كبيرا . لضمان توفر طاقة كفوءة يجب ضبط دورات تشغيل المستشعرات بدقة مناسبة لتحقيق متطلبات ازدحام الشبكة. كما تم تقدير كمية الطاقة المستهلكة في كل عقدة نتيجة التحول بين حالة النشاط وحالة الخمول. تم افتراض نشر أجهزة الاستشعار بطريقة عشوائية. تهدف هذه الدراسة الى تحسين عمر الشبكة المنشورة عشوائيا العشوائي من خلال جدولة تاثير الارسال والاستقبال وحالات السكون على عمليات استهلاك الطاقة في عقد الاستشعار اللاسلكي. تم دراسة ومناقشة نتائج هذه الحالات باستخدام العديد من مقاييس الاداء.

الكلمات المفتاحية : شبكات الاستشعار اللاسلكي, استهلاك الطاقة, PW-MAC , دورات التشغيل, السكون , الاستيقاظ, المحاكاة.

1. Introduction

"Wireless sensor networks" (WSNs) represent a collection of certain number of deployed sensors nodes in a distinct environment. Sensors have ability to sense information, process data and to perform a wireless communication. Each sensor node is commonly powered with a built in limited energy battery. Wireless sensor networks are deployed in environments where it is difficult or impossible to use wired networks. Sensor node has limited storage capacity, limited processing capability, and limited communication bandwidth. The sensor nodes are always deployed in unpractical or hostile environment so, it is impossible or difficult to recharge or replace their batteries [Amandeep and Kamaljit, 2015].

WSNs were deployed in various applications such as surveillance, military observation, healthcare, disaster, examination, intellectual carrying, liberation, goal tracking and environmental managing. Saving energy in WSN becomes a key research challenge. Researchers worked to reduce the energy consumptions in different WSNs applications [Ramanan and Baburaj, 2015].

Recent researches presented that energy savings can be reached by scheduling node's events in WSNs. The sensor node usually operates in one of three states. The consumed energy depends heavily on these states. These states are; reception, transmission and sleep (off stat; without any communication). Recent research indicated that saving sensors energy can be attained by scheduling node's events in high density WSNs [Sonam and Manvinder, 2016]. One of the efficient algorithms to prolong the network lifetime is to manage and control the sensors energy consumption. An efficient management approach is to let the sensor nodes go to sleep and wakeup only when it is required [Hai-Ying, *et al.*, 2011].

In addition to energy saving, the sensing coverage, routing protocols and the deployment techniques were also presented as important significant issues for the WSNs [Sonam and Manvinder, 2016].

This paper is structured to have in Section 2, the sensor nodes. The challenging issues in WSN are discussed in section 3. Sections 4 and 5 are presenting the scheduling and predictive wake up protocols respectively. Duty cycling and The Energy consumption model are reviewed in sections 6 and 7. In sections 8 and 9, the Performance Evaluation and Simulation environment are discussed. Finally, section 10 concludes this paper.

2. Sensor nodes

A sensor represents a special device designed to sense and/or identify certain properties of real objects such as light, temperature, sound, pressure, vibrations, electromagnetic fields and heat. Sensor behaved as an electronic transducer by generating electronic signals to represent any sensed properties of objects. Sensor network usually composed of many sensors deployed over a certain area. Sensor node is capable of gathering certain sensory information, achieve specific processing, and communicate with other sensors in the network. Each sensor node usually includes sensor units, a wireless transceiver, a power source and a microcontroller. Such electronic devices are following the resource constrained phenomena; Sensors have limited transmission range, limited memory, limited energy and limited processing capability [Amandeep and Kamaljit, 2015]. The life of the sensors is mainly depending on the ability of their Batteries. WSN may require a base station or a sink as an upper level to transmit the communication link to the end user. The end user is a center or a person that can make use of the deployed WSN [Ramanan and Baburaj, 2015].

3. Challenging issues in WSN

Many factors affect the process of designing and applying any WSN. These factors must be overcome to achieve reliable communication, good sensing and quick data transmission [Manikandan, et al., 2015],[Senthil and Ponsekar, 2016]. Following are some of these challenges [Amandeep and Kamaljit, 2015].

3.1 Energy: energy represents the main constraint in all the WSNs. Usually operating the sensor node, its data transmission and its data processing are representing the essential energy-consuming processes. Sensors are depending on limited power batteries. In most WSNs applications the ability to replace or recharge the sensor battery in this era is impossible. So, limited energy of the sensor represents a vital task in designing any WSN [Manikandan, et al., 2015]. Great potential research efforts were focused on such issue to increase the lifetime of these networks. The essential reason for the sensor's power consumption is due to the electronic communication processes. The energy consumed in each electronic communication is increased by increasing the transmitted data, increasing the distance between the receiver and the transmitter and the collision between nodes. The routing strategy may also apply to reduce the consumption of the energy [Amandeep and Kamaljit, 2015].

The Hardware devices configuration and selection may be utilized to reach low energy consumption. The good choice of protocols and communication methods can play a role in decreasing the network energy consumption also [Feng, et al., 2014].

3.2 Coverage area: Each sensor node has an ability to achieve certain environment views. Sensors view is limited in accuracy and range. It can offer certain accuracy and cover to a scarce physical object. The coverage area is also an effective design factor in WSNs [Amandeep and Kamaljit, 2015],[Senthil and Ponsekar, 2016].

3.3 Storage: All the designed sensors having small storage size compared with the storages in other modern devices. This restriction makes the design of the WSN requires a special awareness when it used in a high data applications. Limited storage was affected the processes of data communication and data processing [Amandeep and Kamaljit, 2015], [Amandeep and Kamaljit, 2015].

3.4 Scalability: The network scalability represents the ability of the network to deliver a suitable service level when the network size rises. A sensor network in many applications composed of thousands or hundreds of sensor nodes. To ensure reliable operation, a good scalability is required for the wireless sensor networks routing Protocols [Senthil and Ponsekar, 2016].

3.5 Quality of Service: In most sensing applications, the sensed data must be collected and transmitted in a certain epoch of time. The restricted latency for the delivery of the sensed data represents another form of "time constrained requests". The energy conservation which is related to the lifetime of the WSN can be considered in more important manner than the sent data quality in most real applications [Amandeep and Kamaljit, 2015], [Amandeep and Kamaljit, 2015].

4. Scheduling

Sensors are small electronic devices; its power supply unit (batteries) should be very small also. This very small power supply must maintain all the sensor operations carefully. To achieve low energy consumption a suitable routing protocol should be selected to suit each application network. So, the required network lifetime and energy consumption must play main role in selecting a suitable protocol and scheduling its operation duty. The Scheduled protocol may help in keeping only some of the network nodes in sleep state while keeping the others in "active state". A best protocol is to utilize a minimum number of the network sensor nodes to be active at any time. There are many routing protocols were developed to schedule the sensor node duty [Gagandeep and Jasvir, 2014].

There are synchronous and asynchronous types of wake up/sleep scheduling. Subset of the network nodes must wake up to send or receive and all the other sensor nodes must stay in its sleep state. The most energy consumed in WSN is in its sensors active state and in their switching from state to state [Rohan and Poonia, 2014].

5. Predictive Wakeup MAC protocol

Predictive-Wakeup MAC protocol (PW-MAC) was shown to be one of the good "energy-efficient MAC protocols". Its function was heavily based on asynchronous duty cycling process. PW-MAC aims to let the sender wake up before the required receiver wakes up. This protocol lets each sensor node wake up to receive a sent message from others at pseudo-random time. PW-MAC offers a control process to minimize the energy consumption by allowing the senders predict the wakeup times of the receivers. It presents an "on-demand estimation mechanism" to permit accurate estimates [Rohan and Poonia, 2014]. This mechanism has an ability to address the timing challenges effectively; such as unpredictable operating system (hardware) delays and any clock sense. PW-MAC can lead to reach an effective "prediction-based retransmission mechanism" to attain high efficiency even when packets required to be retransmitted or if any kind of collisions happen. The optimum energy-conserving operation can be achieved by putting the sensor transceiver in a sleep mode (low-power) at any time the communication is not necessary [Gagandeep and Jasvir, 2014].

In this protocol which used the "scheduled Pseudo technique", need not all the nodes to be in wakeup state at the same time to transmit data. Any node wakes up will send a little beacon to let other sensor nodes know that it is now ready to receive data packets [Rohan and Poonia, 2014].

In PW-MAC protocol the sender node can use a seed to calculate the wakeup time of the receiver node. The sender node can also change to wake up and sleep shortly before the wakeup of the receiver node [Zahra and Shima, 2012].

6. Duty-cycling

A duty cycle generally means a fraction of a period of time in which a component being in its active state. While a period represents a required time for a message to complete it's "on and off" cycles. Usually, a sensor may have three operating states: reception, transmission and sleep. Previous studies showed that the greatest energy consumption is due to the transmission mode. While the energy consumed in sleep mode is very low. The duty cycle of a node is so important to reduce energy during the sensors communication. Most of network nodes must tend to sleep mode during any time they are not engaged in transmission or reception [Zahra and Shima, 2012].

7. Energy consumption

The main energy consumer in each sensor network was proved to be due to its radio transmission and reception processes. The process of data communication in WSNs spends greatest amount of energy. Minimizing the communication overhead will also reduce the energy consumption [Amandeep and Kamaljit, 2015]. Managing the process of configuring the MAC and networking layer, Data reduction and data aggregation may also help in saving energy. The sensing unit, communication unit (transceiver) and the processing unit represent the essential units to consume energy in each sensor node [Gagandeep and Jasvir, 2014].

One approach to mathematically model the WSN is by a using graph notations G=(S, C), where S denotes the sensors set and C = {(k,s) ⊂ S/D (k,s) <= R}, denotes the nodes connection. D(k, s) denotes the Euclidian distance between the nods (k and s) while, R represents the sensor transmission range. The sensors power consumptions in each transmission state was calculated to about 81 MW, reception is about 30 MW and in Sleep state is about 0.003 Mw [Salim, et al., 2015].

8. Performance Evaluation

Net Logo simulator was used in creating, operating and evaluating a suggested WSN and all its environments in this paper. Net Logo represents a well suited tool in modeling and developing complex systems over time. The suggested environment in this paper was simulated to test the performance of the WSN using "Net logo's graphic design tool" [Touray, et al., 2013].

The PW-MAC performance was also evaluated under different scenarios. In this paper the "throughput", "Data packet delivery ratio" (PDR), "packets loss", "duty cycle", idle cycle and the "Average energy consumption" were used to be our evaluation tools.

9. Simulation environment

A computer simulation means the process of the applying and operating real system or process over time. In this paper, Net Logo (5.1.0) has been used as a network simulator to model and simulate all the suggested scenarios. The Net Logo represents a "multi-agent programming language" [Wilensky, 1999]. It was used to simulate the events like: sending, receiving, forwarding and sleeping. Windows7 was used as an operating system in developing this simulation results. Net Logo simulator was facilitated in this paper to deploy and present the number of "resource constrained nodes" as turtles with their possible connectivity in different areas and random multi hope traffic flow. The simulation test scenario (snapshot) is shown in Figure (1).

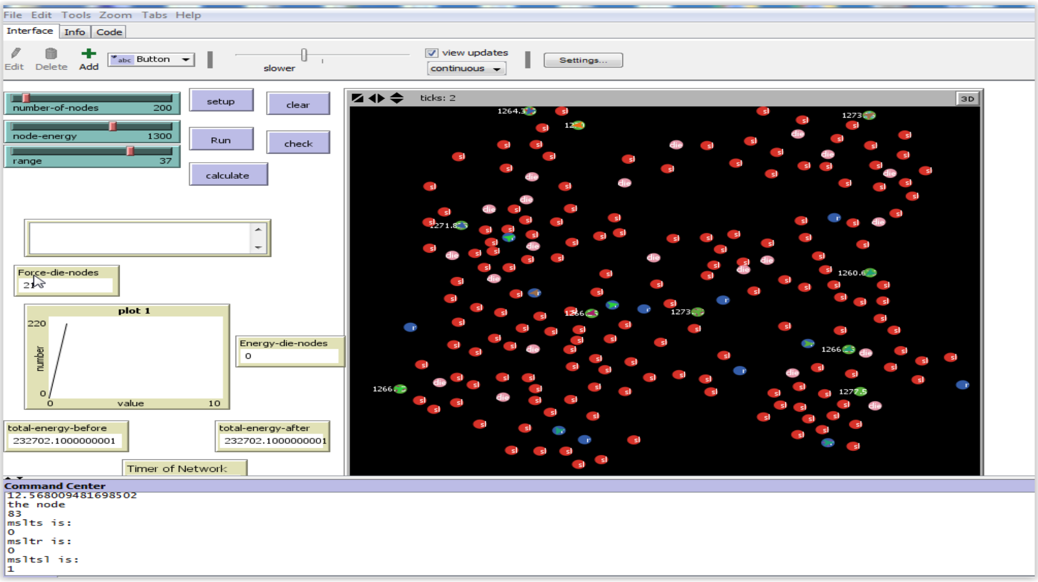

Figure (1): A Simulation snapshot for the developed Net Logo program.

Scenario I

In this scenario, the impact of increasing the implemented number of nodes on the network behavior was tested. The total number of nodes is considered to be m (variable) and randomly deployed. The "throughput", "PDR", "packets loss", "Duty cycle", idle cycle and "end to end delay" were used to estimate this network performance under different number of nodes and random multi hope traffic of 4 hops.

The area size was suggested in this scenario to be 100x100 m^2. The static sensors (50 to 500) nodes were distributed randomly in the simulation environment. All the possible states of the used sensor nodes (receiver, sender or sleep) were chosen randomly according to certain pseudo random numbers suggested. The traffic source was also suggested and generated randomly. In order to perform this scenario, a simulation program was carefully designed to simulate all the possible stages then to implement, test and evaluate the results.

This simulation program was developed using Net logo (5. 1. 0) software applied on a computer with Pentium core Processor i3, with 4GB RAM, 2.5 GHz Speed, and 320 GB Hard Disk. The simulation runs were implemented on Laptop with Windows 8.1 Operating system. The collected results were averaged and graphed in the following figures:

Figure (2) shows the effects of increasing the number of nodes on the throughput and the PDR. Results indicate certain decreases in the PDR value and increase in the throughput value when the number of nodes increases. This figure indicates an increase in the successful transmissions due to the increase in Throughput, and a reduction in the arriving packets to their destinations due to the increasing density which yields high traffic and collision. PDR can be estimated as a percentage of the number of the arriving packets to their destinations and the total generated packets. Increasing the throughput in WSNs and decreasing the energy consumption of the sensor node will improve its lifetime.

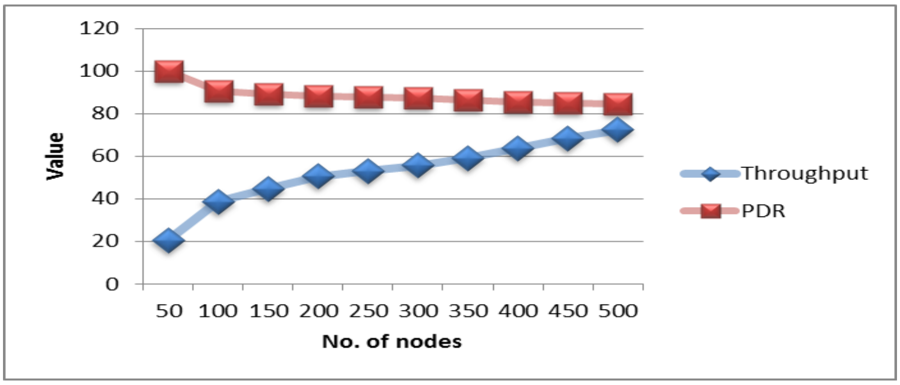

Figure (2): the effects of node numbers on the throughput and PDR.

Figure (3) shows the effect of the increase in the number of nodes on the average packet loss.

Results indicate a directly proportional between the packets loss value and the number of nodes. This is happened due to the effect of the increased traffic and collisions.

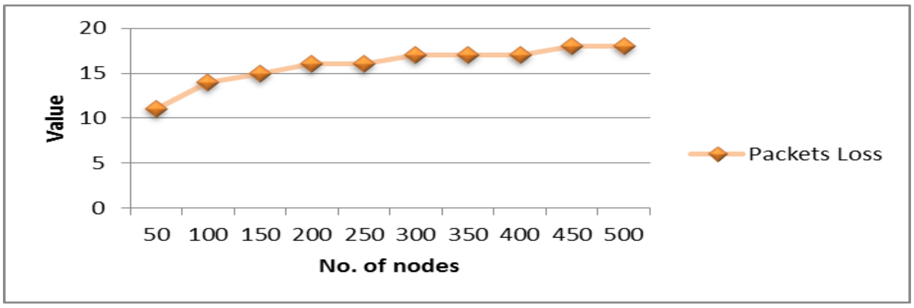

Figure (3): the effect of node numbers on the packets loss.

Figure (4) shows the effects of increasing the number of nodes on the duty cycles and idle cycles.

Results indicate an increase in the duty cycles and the idle cycles when the number of nodes increases. Distance from the sender node to the sink, nodes density and traffics will affect the network consumed energy. The values of the duty cycles are related to the transmission time which affects the consumed energy. Increasing values of the duty cycle means that there are many nodes existing in the network and ready to route data which also increase the consumed energy. To reduce the consumed energy, one must decrease the duty cycle by minimizing the nodes active time stages.

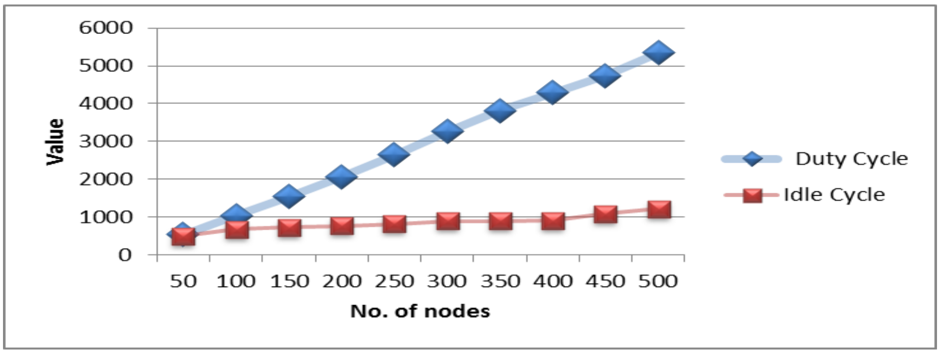

Figure (4): the effects of node numbers on the duty cycles and idle cycles.

Another approach was implemented to compute the network energy consumption. This approach was implemented by varying the number of deployed sensor nodes with different types of traffic sources. It was implemented to investigate the total energy consumption.

Three operation cases were suggested, implemented and evaluated in this approach: in the first case; the program will assign less than half of the network nodes as senders which can be called low level traffic in this study. In the second case the program will assign half of the network nodes to be sender which called normal level traffic. While, in the third case the program will allow the number of the sender nodes to be more than half of the total network nodes number, which is called high level traffic in this paper also.

The program was tested with (20, 100, and 150) randomly deployed sensor nodes. The energy of each node was suggested to be 10000 Joel. A 100x100 m^2 area size was suggested. A random multi hops of 5 hops was also allowed in this scenario. The nodes states as (receiver, sender or sleep) were selected randomly according to certain suggested pseudo random numbers. All other factors and parameters were proposed to be fixed excluding the number of nodes, hopes and the traffic sources. Table (1) presents the simulation results of energy consumed in this approach. When the number of nodes increases the consumed energy will also increases.

Table (1): Simulation results of (PW-MAC) protocol consumed energy

Number of nodes	Energy in high sources	Energy in low sources	Energy in normal sources
20	195341.6	134340.7	156862.3
100	805606.9	528776.4	652473.4
150	6847435.9	1197960.9	2351652.7

Scenario II

As a second approach, the energy consumed in communication process can be analyzed as a communication consumption and switching consumption (switching between sleep and wakeup states). The sensor node consumed energy according to its state; if it's in sending, receiving or sleeping. Actually in each state the nodes consumed different amount of energy. Switching consumption is due changing from state to state.

The simulation program was built to make counters to estimate the number of node states at a complete run cycle (certain simulation time). For each node counter will count how many times node being in sending state, receiving state and how sleeping state. The counter can also count how many times switching was happened from state to state. These numbers can be changed into consumption values. Figure (5) shows an algorithm to count the nodes states and the switching process.

To implement and test this procedure effectiveness, counting the switching node’s states simulation model was built and applied. This model was suggested to contain 14 nodes. A 100x100 m^2 was suggested for the area size and the static sensor nodes were distributed randomly. The state of any sensor node (receiver, sender or sleep) was chosen randomly according to certain suggested pseudo random numbers approach. A 5- random multi-hop was allowed and applied with normal traffic. Sample of the average resulted information was listed in the table (2).

```
                         Nodes switching Algorithm
Input:  PW-MAC nodes
Output:   switching states counter
Begin:
Ask  turtles
    Begin
        ask turtles-here
            begin
               ;{" R:  receiving state"}
             if (who = "R" or color = blue)
                begin
                  if timer > RP
                   begin
                       if (who = "R" or color = blue)
                                  ;{"node switches from receive to receive"}
                   set RtoR  ←  RtoR + 1
                      if (who = "S" or color = green)
                                  ;{"node switches from receive to send"}
                       set RtoS    ←  RtoS +1
                         if (who = "sleep" or color = red)
                                  ;{"node switches from receive to sleep"}
                        set Rtosleep  ←  Rtosleep + 1
                   end
                 end
                   ;{ "S: sending  state"}
           if (who = "S" or color = green)
               begin
                  if timer > SP
               begin
                   if (who = "S" or color = green)
                               ;{"node switches from send to send"}
                     set StoS    ←  StoS + 1
                    if  (who = "R" or color = blue)
                                  ;{"node switches from send to receive"}
                      set StoR  ←     StoR + 1
                       if (who ="sleep" or color = red)
                                  ;{"node switches from send to sleep"}
                       set Stosleep  ←   Stosleep + 1
                  end
              end
           if (who = "sleep" or color = red)
           begin
             if timer > sleepP
          begin
               if (who = "S" or color = green)
                              ;{"node switches from sleep to send"}
                 set sleeptoS    ←  sleeptoS + 1
               if (who = "R" or color = blue)
                              ;{"node switches from sleep to receive"}
                set sleeptoR  ←  sleeptoR + 1
               if (who = "sleep" or color = red)
                                ;{"node switches from sleep to sleep"}
                 set sleeptosleep   ←  sleeptosleep + 1
           end
        end
    end
End.
```

Figure (5): algorithm to count the nodes states and their switching process.

Table (2): average nodes states numbers

No. of node	Sender to Receiver	Sender to Sender	Sender to Sleep	Receiver to Receiver	Receiver to Sender	Receiver to Sleep	Sleep to Sender	Sleep to Receiver	Sleep to Sleep
1	5	4	7	3	4	5	6	5	6
2	6	4	6	4	6	3	4	4	8
4	7	5	6	5	6	4	2	3	7
6	6	7	5	5	8	2	7	2	3
8	5	6	5	4	5	3	4	5	8
10	8	5	4	5	4	3	4	3	9
12	5	5	6	2	4	7	6	5	5
14	8	3	5	3	6	5	6	5	4

As a sample node number 6 was selected and its transition rate diagram was plotted in figure (6). The three possible states were labeled as sender, receiver and sleep. Each arrow indicates the possible transition from state to state. The numbers under each arrow represent the number of the switching to this state while the numbers above represents the probability of switching from state to state.

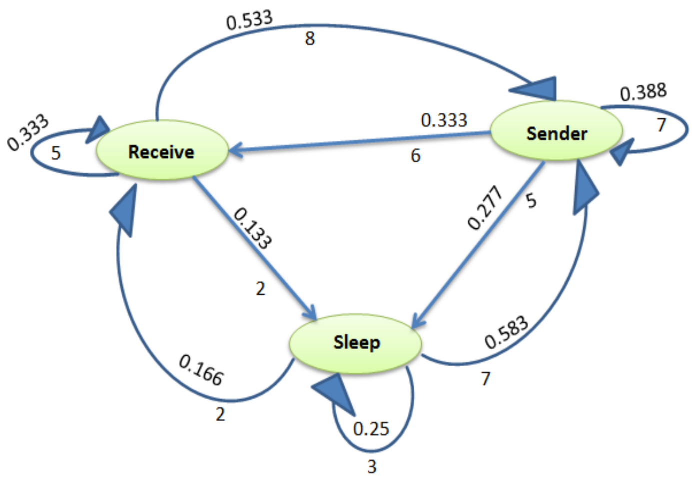

Figure (6) shows the switching states for node 6 and its states change probabilities.

Depending on these values, the total amount of consumed energy can be estimated by applying the following equations:

node consumed energy = consumed energy in sending state+ consumed energy in receiving state+ consumed energy in sleeping state + consumed energy in switching from sending to sleep+ consumed energy in switching from sleeping to receive + consumed energy in switching from sleeping to send + consumed energy in switching from receiving to sleep.

10. Conclusion

MAC protocols represent the greatest approach to manage the energy of the network in an efficient manner. The duty-cycle based MAC protocols reduced the energy consumption due to the idle listening by enabling node to go periodically to sleep mode. In the existing duty cycle protocol there is energy wastage in changing the traffic due to unnecessary wakeup node. The best approach to decrease the sensors wasted energy in WSN is by switching maximum possible number of the sensor nodes into sleep mode. The consumed energy will be increased when the density of the sensor nodes increased due to the growing of the traffic sources.

In this paper an energy consumption model for each sensor node under different operating states and different transition states was suggested, implemented and evaluated using a multi-agent programming language (Net Logo). PW-MAC was proven to be applicable in WSN and useful in saving its consumed energy which leads to prolong the network life time.

An increase in the consumed energy with the increasing of the network traffics was recorded. When the traffic sources are being in its high case, the energy consumption found to be lower and better than its values in other two traffic sources cases. The energy consumption is directly proportional to the duty cycles values. To reach low energy consumption the network designer must try to decrease the duty cycles.

The best approach to decrease the consumed energy of sensor nodes in a static WSN can be achieved by switching most of the network nodes to sleep mode. The accurate manner to achieve this approach is by supplying all the network nodes by up to date information about the action and the behavior of all their neighbor nodes. Such information must be exchanged among all the network nodes.

The simulation results indicated certain increase in energy consumption, decreases in the PDR value, increase in packets loss, increase in the duty cycles, increase in the idle cycles and increase in the throughput value when the number of nodes increases. A suggested model can be used to estimate the consumed energy in each WSN. The scheduling and energy management process can help in reducing the sensor nodes consumed energy.

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