

Performance Evaluation of the MPW-MAC Protocol for Wireless Sensor Networks

Saad Talib Hasson
University of Babylon
Saad.aljebori@gmail.com

Fawziya Waleed Al-Hayali
University of Babylon
fawziah.w@gmail.com

Abstract

Recently Wireless sensor Networks (WSNs) take interesting researches due to their important and crucial applications. WSNs have limited energy so all researches focused in designing routing algorithms to save energy and to make each one operating for longer possible time. This paper was implemented the developed a modified predictive-wakeup MAC protocol (MPW-MAC) using NetLogo simulators. Also was tested the behavior of the MPW-MAC in relation to the Data Packet delivery Ratio (PDR), average packet loss, average throughput, average delivery latency, and average duty cycle. One important challenge in the WSNs is the energy consumption. A new approach was designed to estimate the energy consumption. The simulation results show improvements in Data Packet delivery Ratio (PDR), average packet loss, average throughput, average delivery latency, and average duty cycle. Nodes distribution, selecting the nodes states, and wakeup times of nodes and the interval wakeup are randomly chosen. Also the result indicates that the MPW-MAC protocol reduces the energy consumption and the number of the switching between states in the node will effects on the amount of the energy consumed by the node.

Keywords - WSN, Simulation, MPW-MAC, Energy consumption.

الخلاصة

قت شبكات الاستشعار اللاسلكية اهتماما متزايدا من الباحثين نتيجة لأهميتها وتطبيقاتها الحيوية. تمتاز هذه الشبكات بمحدودية الطاقة ولذلك فإن اغلب البحوث قد ركزت على تصميم بروتوكولات لحفظ الطاقة وجعلها تعمل لأطول فترة ممكنة. في هذا البحث تم تطبيق البروتوكول المعدل (MPW-MAC) بأستخدام لغة المحاكاة (NetLogo). كما تم اختبار سلوك البروتوكول وعلاقته مع نسبة تسليم حزم البيانات (PDR)، فقدان الحزم، الانتاجية، متوسط دورة عمل، و الوقت المستغرق لتسليم حزم البيانات. أحدى التحديات المهمة في هذا النوع من الشبكات هو استهلاك الطاقة. تم تصميم طريقة جديدة لتقدير استهلاك الطاقة. بينت النتائج المحاكاة وجود تحسين في نسبة تسليم حزم البيانات (PDR)، فقدان الحزم، الانتاجية، متوسط دورة عمل، و الوقت المستغرق لتسليم حزم البيانات. عملية توزيع العقد، اختيار حالة كل عقدة و أوقات استيقاظ العقد والفواصل أوقات الاستيقاظ تم اختيارها بشكل عشوائي. كما بينت النتائج أن البروتوكول (MPW-MAC) يقلل أستهلاك الطاقة وعدد مرات تحويل بين حالات العقدة قد يؤثر على كمية الطاقة المستهلكة في كل عقدة.

الكلمات المفتاحية : شبكات الاستشعار اللاسلكي، المحاكاة، بروتوكول MPW-MAC، استهلاك الطاقة

1. Introduction

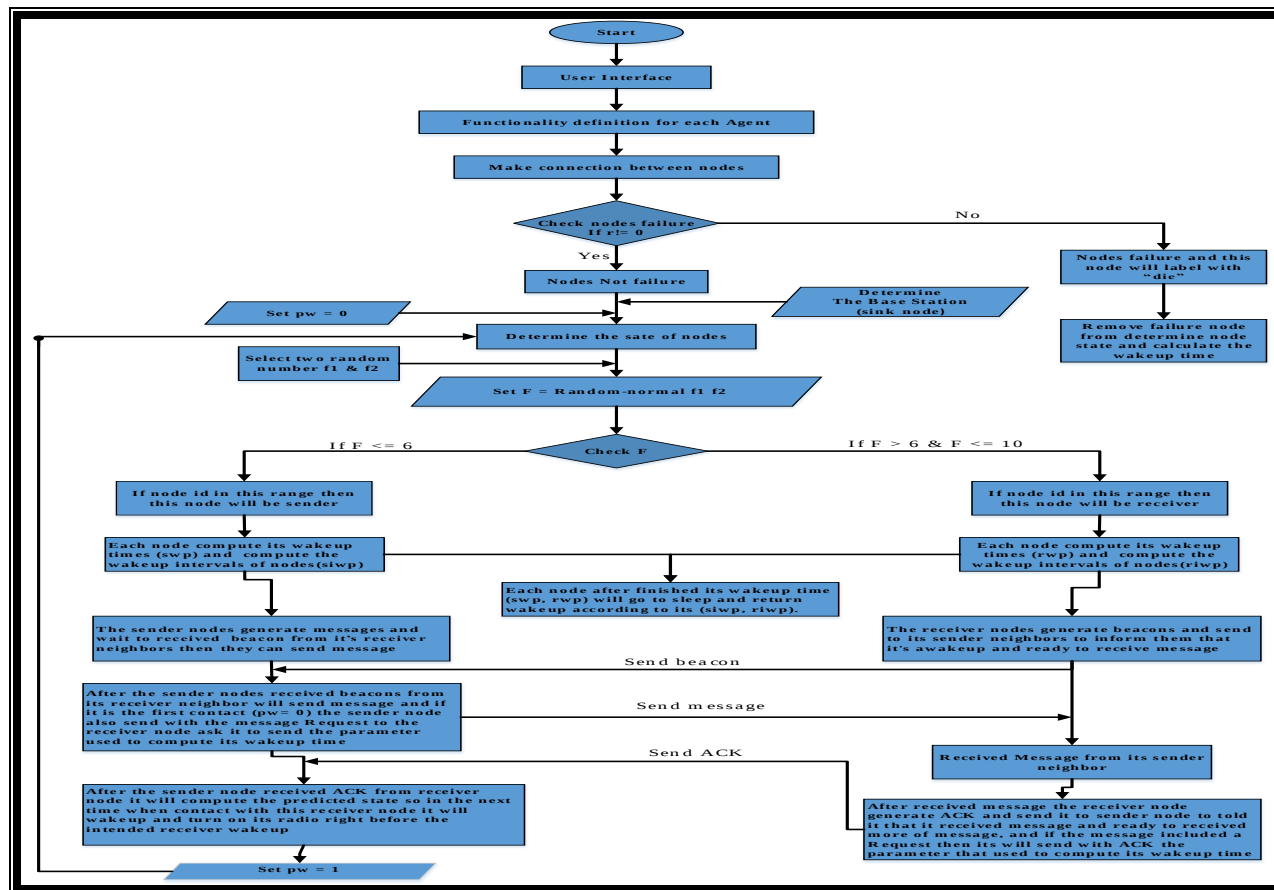
Wireless sensor networks (WSNs) have many attracted research and applications fields. The energy efficiency issue is one of its important design challenges. Sensor nodes have limited lifetime since it powered by batteries. Even with additional source of energy from the external environment, it was still limited resource that must be consumed wisely [Alippi *et al*, 2009]. Sensor nodes must be operated as long as possible. An efficient approach for achieving high energy efficiency in WSNs is a duty cycling. Each node can periodically being sleep and wake up. Nodes go to sleep state when there are no packets need to be sent, this helps in reducing the energy consumption at idle listening. The

node's duty cycle is referred to the percentage of time a node is awake up. Duty-cycling can improve the energy efficiency of a WSN by reducing two of the most significant causes of unnecessary energy consumption which are idle listening and overhearing [Fei Tong, 2012]. There are several important energy efficiency MAC protocols have been suggested. Some of these MAC protocols are synchronous communication schemes, while the other MAC protocols are asynchronous communication scheme [Wei Ye *et al*, 2004]. The advantage of asynchronous transmission makes the protocol design simple and effective, is that both the sender and the receiver can maintain their own listen-sleep scheduling and do not require whole networks synchronization [Hao Liu *et al*, 2012]. Sensor nodes in synchronous protocols will be wake up only during the common active time intervals to exchange packets. Substantial energy can be saved, but this require strict time synchronization and impose high overhead. Conversely asynchronous protocols maintain independent wake up schedule and thus eliminate the overhead for synchronization. Asynchronous MAC protocols are efficient either in light traffic loads or high traffic loads [Ye Liu, *et al*, 2012] . This paper focuses on evaluating the behavior and performance of the MPW-MAC for wireless sensor networks. Simulation is the imitation of the operation of a real-world process or system over time. It is more important when the actual system is more difficult and expensive to build and reconfigure frequently. Therefore, the simulation can be found as a tool to evaluate the performance of the system under many different restrictions and configurations that may be occurred in the real time. Simulation was used to reduce the cost, risk and failure states in the building operation of the actual system [Mohsen, 2011] . There are different network simulators with different features used and applied. As NetLogo represents multi agent programming language, it was utilized to simulate and operate different designed WSNs with the old and modified protocols. This paper will use NetLogo simulator (version 5.0.4, 2013).

2. The MPW-MAC protocol for wireless sensor networks

The energy efficiency issue is a challenge, as sensor nodes would be operating longer. Sensor nodes must be operating as long as possible. Achieving long battery life is important, since it may be difficult to replace the batteries. There are several important energy efficiency MAC protocols have been suggested. One of these protocols is MPW-MAC protocol which is a modified predictive-wakeup MAC protocol (MPW-MAC) is improvement on the existing PW-MAC protocol. The MPW-MAC protocol applies the concept of the prediction state as following: when the receiver node wakeup it sends a short beacon in order that other sender nodes know that it wake up and ready to receive a data packet. Then sender node can send a data packet and ask for more information from the receiver node like mean for the random distribution equation used by receiver to generate the wakeup time. Sender node in MPW-MAC can then use this mean in the random distribution equation to predict wakeup time of receiver node, and thus sender node sleeps and wakeup slightly before the receiver node is a wakeup. Using the random variable for wakeup time and interval wakeup time of nodes is more efficient than using the random number. Also there is different between the random number and the random variable since the random variable can reflect the behavior of wireless sensor network and when represent the random variable graphic, we can see the reflect of its behavior.. Every random distribution has different graphic represent that reflect different behavior.

So by using random distribution we can decide which random distribution equation we want to reflect behavior that needed it. Also due the design of the MPW-MAC improves the performance of the WSN when there is random network and under high traffic load. Figure (1) shows flowchart of the design and implementation of MPW-MAC on the wireless sensor network



Figuer1: The design and implementation of MPW-MAC on the wireless sensor network

3. Test the performance of MPW-MAC protocol

There are many different parameters effect the performance of the (MPW-MAC) protocol such as: number of nodes in the network, size of area topologies, the number of hops it takes to deliver the message, and traffic rates. Since the traffic source is important parameter to the performance of the WSNs. In order to prove the efficiency of the protocol, the following scenarios will test the protocol behavior with certain performance metrics.

Many scenarios were implemented by changing the type of traffic source in each scenario. These scenarios test the effects of varying traffic source on the MPW-MAC protocol. The effectiveness of traffic source was studied with a different number of nodes. In this case study applies the simulation program of WSN with four type of traffic source: optimistic, normal or most likely, random and pessimistic. In the optimistic case the number of source is less than from the half number of sender nodes in the network which represented the best behavior of the network. In the normal case the number of

source equals to the half number of sender nodes in the network. In the random case the number of source is random number but this number not exceeds the number of sender nodes. In the pessimistic case the number of source equals to the number of the sender nodes which represented the worst behavior of the network. The area size in these scenarios was 600x600 m². Nodes distribution, selecting the nodes states, and wakeup times of nodes and the interval wakeup are randomly chosen. The number of hops in these scenarios is 5 hops as maximum.

Each scenario was run and simulated in an operation manner (30) times in order to get near real results from simulation programs. The resulted information was listed in tables 1, 2, 3 and 4, which indicated the performance of MPW-MAC protocol under different performance metrics.

Table1: Optimistic case

No. of Node	Average PDR %	Average Packet Loss	Average Throughput	Average Delivery Latency	Average Duty Cycle
200	90.0931	14.25	54.3727	0.536362	1033.919
400	87.1893	15.983	70.0302	0.98066	3240.061
600	85.5492	16.973	79.52078	1.569019	5004.638
800	83.9802	18.943	86.7387	2.504494	7342.388
1000	80.5602	20.654	121.1843	3.799923	9000.406

Table2: Normal case

No. of Node	Average PDR %	Average Packet Loss	Average Throughput	Average Delivery Latency	Average Duty Cycle
200	86.24811	16.073	49.345	0.998066	2061.851
400	84.49649	17.076	61.9343	1.518636	4285.981
600	80.46317	18.098	75.7621	3.518636	6279.417
800	78.03434	20.78	80.9698	5.911033	8203.54
1000	76.7072	22.782	90.84188	7.006284	10575.98

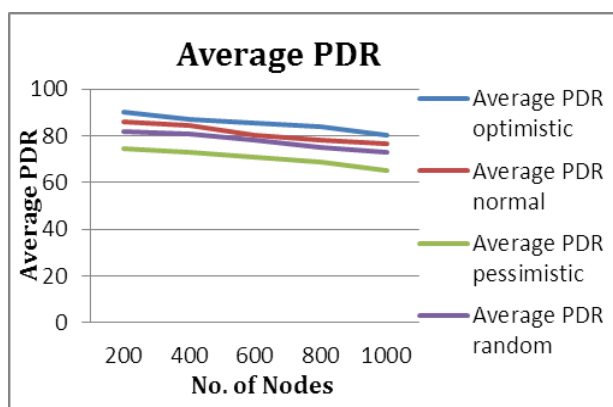
Table3: Random case

No. of Node	Average PDR %	Average Packet Loss	Average Throughput	Average Delivery Latency	Average Duty Cycle
200	81.97283	17.987	40.956	0.938066	2142.111
400	80.98161	19.9561	59.932	1.25933	4402.742
600	78.33973	23.471	70.94391	3.33321	6491.239
800	75.21798	25.098	84.17641	6.01955	8661.556
1000	72.81798	27.0432	89.84188	8.7309	10800.84

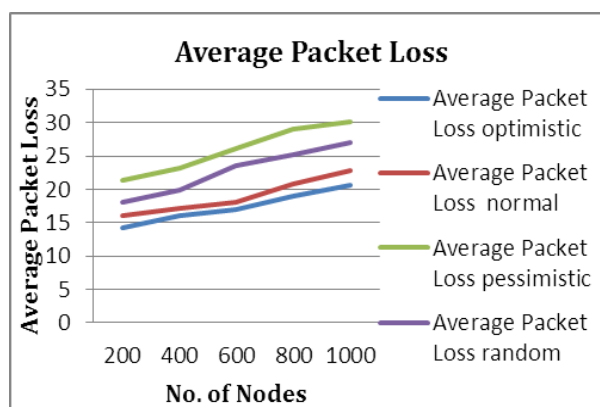
Table4: Pessimistic case

No. of Node	Average PDR %	Average Packet Loss	Average Throughput	Average Delivery Latency	Average Duty Cycle
200	74.4302	21.2871	35.5486	1.9.64221	3261.684
400	72.9137	23.098	50.6791	2.981109	5587.971
600	70.9078	26.0432	65.0345	4.49929	7546.055
800	68.8402	28.943	70.59075	7.212485	9515.932
1000	65.2457	30.0981	75.94391	11.51727	12575.99

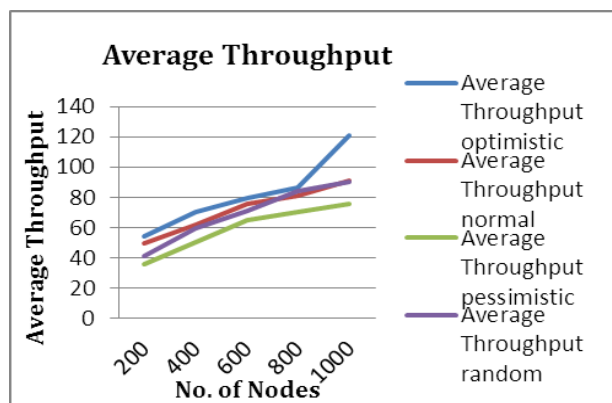
According to the results mentioned in tables (1, 2, 3 and 4) of the simulation program, we noted that some of the performance metrics was changed with the changing of the traffic source. The results in tables (1, 2, 3 and 4)) are graphed figure 2 (A to E) show the relationship between the network metrics and the effects of varying the traffic source on the behavior of MPW-MAC protocol.



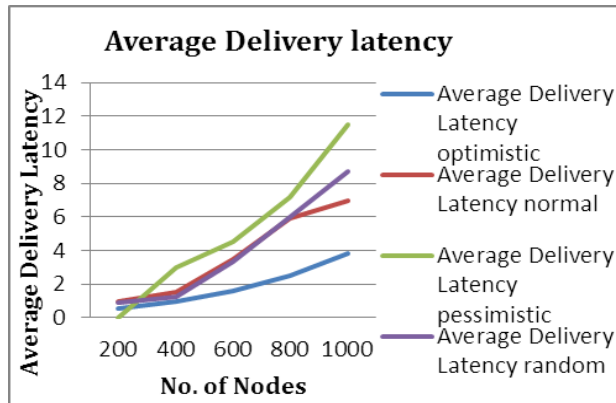
A: Relationship between traffic source and average PDR with a different No. of Nodes



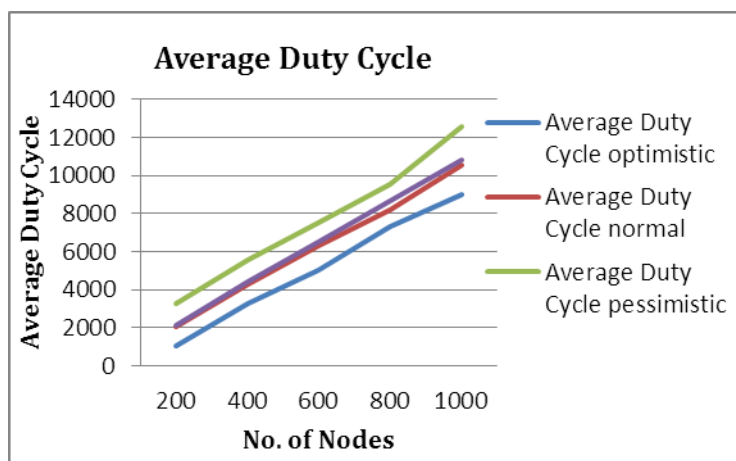
B: Relationship between traffic source and average packet loss with a different No. of Nodes



C: Relationship between traffic source and average throughput with a different No. of Nodes



D: Relationship between traffic source and average delivery latency with a different No. of Nodes



E: Relationship between traffic source and average duty cycle with a different No. of Nodes

Figure2: Show the performance of the MPW-MAC protocol with different performance metrics

The following lines show the effects of the traffic source on the performances of the MPW-MAC protocol.

- When the traffic source was being in its optimistic case, the MPW-MAC protocol has better performance in terms of the PDR, average packet loss, average throughput, average delivery latency, and the average duty cycle than its values when the traffic source is in its pessimistic case.
- When the traffic source was being in its normal case, its performance was closed to the performance when the traffic source is in its optimistic case. While the performance when the traffic source is in its random case sometimes was found to be closed to the performance when the traffic source is in its optimistic case and sometimes was found to be closed to the performance when the traffic source is in its pessimistic case, this depends on the random number which represents the traffic source.
- The number of the switching between the node states increased with the increasing of the traffic source since nodes need to change their state to pass the messages from source to the next closest suitable station.

4. The energy consumption in the MPW-MAC protocol

To compute the energy consumption in MPW-MAC protocols, a developed approach was suggested. In this approach the energy consumption in (each protocol that makes switching between sleep and wakeup) is divided in to three parts. **First:** - Node Consumption: the energy consumed according to the state of nodes if its sender or receiver or sleep in each states the nodes consumed different amount of energy. **Second:** - Communication Consumption: the energy consumed from nodes to generate beacons,

acks, and messages. **Third:** - Switching Consumption: the energy consumed from nodes due switching between the nodes states. So energy consumed will calculate as:

Energy consumeds

$$\begin{aligned}
 &= \sum_{i=0}^n [\text{energy of node}(i) \text{ in its state} * \text{counter of node state}] \\
 &+ \sum_{i=0}^n [\text{energy of generate (beacons, acks, messages)} * \text{number of (beacons, acks, messages)}] \\
 &+ \sum_{i=0}^n [\text{energy of node (i) due to switching between node's state}]
 \end{aligned}$$

This paper will focus on the energy consumed due to the Switching Consumption. In order to know how much the energy consumed due to the switching between the node's states, a nine counters have define for each node to count the switching state and used these counters to calculate the energy consumed. Each node state has different parameter that identify its state like in the receiver state the node will label with "r" and its color is blue, its wakeup time is "rwp", will the counter to count the switching between states are [**mrtr**: node be receiver again, **mrts**: node switches from receiver to sender, **mrtsl**: node switches from receiver to sleep state]. When node in the sender state it will label with "s" and its color is green, its wakeup time is "swp", will the counter to count the switching between states are [**msts**: node be sender again, **mstr**: node switches from sender to receiver, **mstsl**: node switches from sender to sleep state]. When node in the sleep state it will label with "sl" and its color is red, its wakeup time is "slt", will the counter to count the switching between states are state [**msltsl**: node be in sleep state again, **mslts**: node switches from sleep state to sender state, **msltr**: node switches from sleep state to receiver state]. Figure (3) is the procedure that counts how many switches happen for each node

Algorithm counter of the switching between the node's states

Input: The input to this procedure is the nodes out from MPW-MAC procedure

Output: the output is the nodes with counter for its switching states

Begin:

```

Ask nodes
begin
  ask nodes-here
  begin
    if (label = "r" or color = blue)
      begin
        if timer > rwp
          begin
            if (label = "r" or color = blue)
              set mrtr ← mrtr + 1
            if (label = "s" or color = green)
              set mrts ← mrts + 1
            if (label = "sl" or color = red )
              set mrtsl ← mrtsl + 1
          end
        end
      end
    if ( label = " s" or color = green)
      begin
        if timer > swp
          begin
            if (label = "s" or color = green)
              set msts ← msts + 1
            if (label = "r" or color = blue)
              set mstr ← mstr + 1
            if (label = "sl" or color = red)
              set mstsl ← mstsl + 1
          end
        end
      end
    if (label = " sl" or color = red )
      begin
        if timer > slt
          begin
            if (label = "s" or color = green)
              set msmts ← msmts + 1
            if (label = "r" or color = blue)
              set msltr ← msltr + 1
            if (label = "sl" or color = red)
              set msmtsl ← msmtsl + 1
          end
        end
      end
    end
  end
end

```

End.

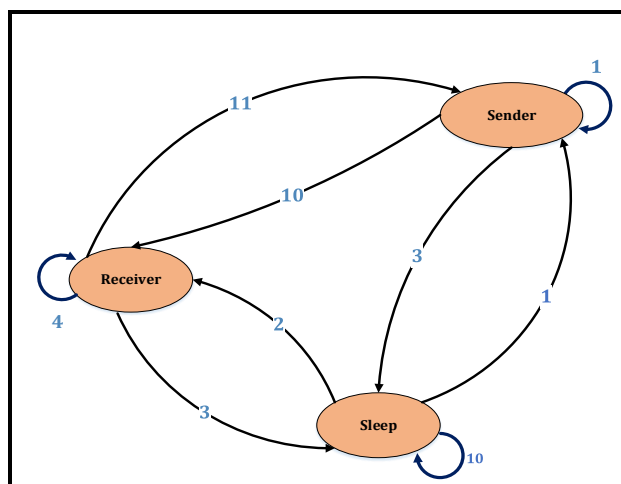
Figure3: The procedure of counting the switching between node's states

To test the effectiveness of this procedure that counting the switching node's states, the following scenario was applied. The scenario contains 10 nodes; the area size in this scenario was $100 \times 100 \text{m}^2$. Nodes distribution, selecting the nodes states, and wakeup times of nodes and the interval wakeup are randomly chosen. The traffic source in these scenarios is normal case. The number of hops in this scenario is 3 hops as maximum. Each scenario was run and simulated in an operation manner (30) times in order to get near real results from simulation programs. The resulted information was listed in the table 5.

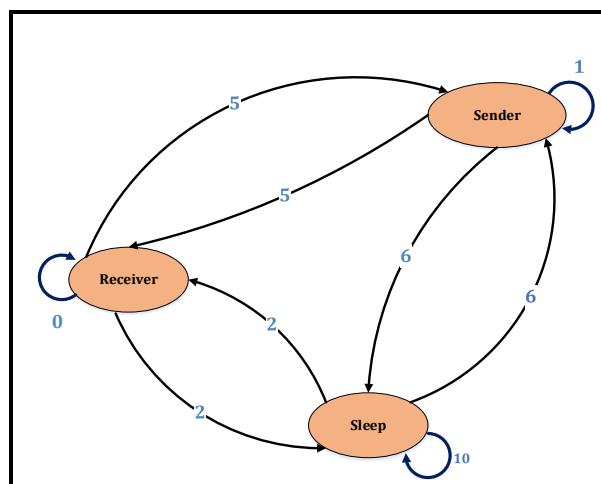
Table5: Simulation results of counting switching between the node's states

Nodes	Sender to Sender	Sender to Receiver	Sender to Sleep	Receiver to Sender	Receiver to Receiver	Receiver to Sleep	Sleep to Sender	Sleep to Receiver	Sleep to Sleep
1	3	1	2	1	0	4	9	4	11
2	1	8	1	9	2	6	0	2	9
3	0	8	5	11	3	2	1	4	7
4	2	3	5	9	3	4	9	0	13
5	6	4	4	5	0	3	0	2	12
6	1	10	3	11	4	3	1	2	10
7	3	4	9	11	2	6	1	0	2
8	2	8	2	9	3	5	5	4	1
9	4	6	3	3	3	9	1	0	7
10	1	5	6	5	0	2	6	2	10

The results in table 5 are graphed in the following figures to show the counting switching between the node's states. Figure4 (A &B) shows how the nodes switch their state in order to delivered messages from source to the best station. This figure drown the switches of two nodes, which are the node 6 and the node10.



Switches states of node 6



Switches states of node 10

Figure4: the switching state of two nodes

The above figures count the number of switching of two nodes (node 6, node 10), the node 6 return to the sender state (msts) is equal to 1, the node switches from sender to receiver state (mstr) is 10 times, the node switches from sender to sleep state (mstsl) is 3 times. The node 6 return to the receiver state (mrtr) is equal to 1, the node switches from receiver to sender state (mrts) is 11 times, the node switches from receiver to sleep state (mrtsl) is 3 times. The node 6 return to the sleep state (msltsl) is equal to 10, the node switches from sleep to sender state (mslts) is 1 times, the node switches from sleep to receiver state (msltr) is 2 times.

After counting the number of the switching state of each node like in the above figures, now will apply the following equations to compute the energy consumption of the node.

Energy in sender state:-

$$\text{Energy} = [1.875 * \text{send}] + [1.4 * \text{type of traffic source}] + [(1.875 * 0.01 * \text{msts}) + (1.875 * 0.01 * \text{mstr}) + (1.875 * 0.01 * \text{mstsl})]$$

Send is the counter that count how many node be in the sender state.

Energy in receiver state:-

$$\text{Energy} = [1.3 * \text{res}] + [(1.4 * \text{res}) + (1.4 * \text{type of traffic source})] + [(1.3 * 0.01 * \text{mrts}) + (1.3 * 0.01 * \text{mrtr}) + (1.3 * 0.01 * \text{mrtsl})]$$

Rec is the counter that count how many node be in the receiver state.

Energy in sleep state:-

$$\text{Energy} = [0.045 * \text{sle}] + [(0.045 * 0.01 * \text{mslts}) + (0.045 * 0.01 * \text{msltr}) + (0.045 * 0.01 * \text{msltsl})]$$

Sle is the counter that count how many node be in the sleep state.

So now the total energy consumed will be calculated as:-

$$\text{Energy} = \sum_{i=0}^n [\text{Energy of node(i) in sender stat} + \text{Energy of node(i) in receiver state} + \text{Energy of node(i) in sleep state}] .$$

We will apply these equations on the node6 and node 10 that drown in the figures4 to show the energy that consumed due to the switching states and also the total energy consumed.

Energy consumed due to switching state of node 6= 0.50235 Joel.

Total energy consumed of node 6= 140.35735 Joel

Energy consumed due to switching state of node 10=0.3241 Joel.

Total energy consumed of node 10 =118.8491 Joel.

The switching state between wake up and sleep is important issue since it's saving the energy consumed by the node due to the idle listening. But also we need to make this switch between wakeup and sleep state to be more efficient to avoid a waste of the energy on this switching. The result shows the energy consumed of the node 6 due to the switching state is higher than the energy consumed of the node 10 due to the switching

state since the number of the switching between states in the node 10 is less than the number of the switching between states in the node 6.

5. Conclusion

The main effort of this paper is to implement and test the performance of the modified predictive-wakeup MAC protocol (MPW-MAC) for wireless sensor networks. The developed modified predictive-wakeup MAC protocol (MPW-MAC) was implemented and tested using NetLogo simulators. The recorded results showed an improvement in the performance of the MPW-MAC protocol in Data Packet delivery Ratio (PDR), average packet loss, average throughput, average delivery latency, average duty cycle, and the energy consumption. The simulation results in this study showed that when the traffic source was being in its optimistic case, the MPW-MAC protocol has better performance in terms of the PDR, average packet loss, average throughput, average delivery latency, and the average duty cycle than its values when the traffic source is in its pessimistic case. When the traffic source was being in its normal case, its performance was closed to the performance when the traffic source is in its optimistic case. While the performance when the traffic source is in its random case sometimes was found to be closed to the performance when the traffic source is in its optimistic case and sometimes was found to be closed to the performance when the traffic source is in its pessimistic case, this depends on the random number which represents the traffic source. According to the developed approach that used to estimate the energy consumption, we found that the energy consumed in each node due to the switching between the nodes states is too much less than that energy consumed when one keeps that node wakeup and not switched to sleep state. Finally the result shows that the number of the switching between the node states increased with the increasing of the traffic source since nodes need to change their state to pass the messages from source to the next closest suitable station.

References

- Alippi , C.; Anastasi, G.; Francesco, M.Di Roveri, M. **“Energy Management in Wireless Sensor Networks with Energy-hungry Sensors”**, in: IEEE Instrumentation and Measurement Magazine Vol. 12, N. 2, April 2009, pp. 16-23, 2009.♾
- Fei Tong, **“PRA-MAC: A Pipelined, Routing-Integrated and Loosely-Addressing MAC for Wireless Sensor Networks”**, University of Victoria, Victoria, BC, Canada, Dec. 14, 2012.
- Hao Liu, Fulong Jiang and Guoliang Yao, **“An Appointment Based MAC Protocol for Wireless Sensor Networks”**, in: International Conference on Cyber-Enabled Distributed Computing and Knowledge Discover, 2012.
- Mohsen H. Hussein, **"Building a Computer simulation Model to Enhance the Utilization of Railway Network in Iraq (A case Study of Baghdad – Karbala Line)"**, MSc. Thesis, College of Science, Babylon University, 2011.
- Wei Ye, John Heidemann, and Deborah Estrin, **“Medium Access Control with Coordinated Adaptive Sleeping for Wireless Sensor Networks”**, in: IEEE/ACM TRANSACTIONS ON NETWORKING, VOL. 12, NO. 3, JUNE 2004.
- Ye Liu, Fulong Jiang, Hao Liu and Jianhui Wu, **“SC-MAC: A Sender-Centric Asynchronous MAC Protocol for Burst Traffic in Wireless Sensor Networks”**, 978-1-4673-4728-0/12/\$31.00 ©2012 IEEE, 2012.