New Cost-efficient Approach Based on Cross-Layer Protocol in Wireless Sensor Networks

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***Abstract*—Nowadays, the minimization of energy consumption in terms of cost and lifetime is the main preoccupation in the recent research studies. This paper deals with the proposition of a Power Consumption Protocol-Physical, Mac and Network (PCP-PMN) based on cross-layer for wireless sensor networks which uses three layers (Physical, Mac and Network). Our PCP-PMN algorithm presents the minimum transmission power between nodes at the physical layer. It uses this minimum transmission power as a metric at the network layer for the proposed routing based on LEACH protocol and performs scheduling at the mac layer for the proposed hybrid spread spectrum. The evaluation results mark that the implementation of our proposed approach preserves more energy and leads to a better performance system.**

I. Introduction

Wireless sensor networks (WSNs) are one of the most important elements in the internet of things (IoT) paradigm, as they are a sensor nodes battery powered devices. Accordingly, energy efficiency is one of the determining factor for lifetime and a major research topic of WSNs.The limitation of energy in the sensor nodes which demanded every functionality of WSNs to be energy efficient. In fact, we must face concern how to reduce the energy consumption to extended the network lifetime. So, optimization of energy consumption in Wireless Sensor Network nodes has become a critical challenges to researchers. In this context, an increasing number of research works has been conducted in order to propose a wide solutions to the energy-saving problem. Thus, all layers of protocol architecture influence the energy consumption. Thus, using interaction between these layers by a cross layer design will result in an efficient energy and improve the overall network performance. Indeed, recent papers on WSN reported in (1), (2) based on cross layer result progress in term of energy preservation. This paper makes the following key contributions. First, at the level of physical layer, the minimum transmission power between nodes is obtained and gives this node where it is obtained a higher priority. Second, at the network layer, we used the parameter obtained previously as a metric to make elect cluster-head and make improvement of proposed routing algorithm based on LEACH protocol. Third, at the level of Mac Layer, PCPPMN treats the scheduling by using proposed hybrid spread spectrum. To evaluate the performance of our approach, we simulated our WSN on two platforms using TOSSIM the simulator of TinyOS and Contiki OS the COOJA Simulator. PCP-PMN economizes energy and prolongs the life cycle of the entire network. The originality of our approach compared to others cross-layer energy optimization approaches is that we implemented and tested our algorithm on two platforms to show and prove the efficiency of PCP-PMN. So, its not easy to transfer to another operating system because we need a new architecture, programming language, communication protocols, scheduling and memory management.

The remainder of this paper is organized as follows. In background and related works Section, we overview layered architecture reviews of existing cross-layer scheme and some preliminaries and concepts used in our approach. Section III presents our Power Consumption Protocol-Physical, Mac and Network (PCP-PMN) principle. Section IV presents the experimentation steps and results. Finally, Section V concludes the work.

II. Background and Related Works

In this section, we will present a brief description of some basic concepts used in literature and some related works in relation to our work to help understanding the contributions of the paper. All layers of WSN protocol stack influence the power consumption since WSN nodes have stiff energy constraint because they are powered by batteries. Therefore, using interaction between these layers by a cross layer design will result in an efficient energy. In this paper, we propose power consumption protocol based on cross-layer for Wireless Sensor Networks.

A. Background Description

Firstly, we present the layered architecture to understand the cross-layer approach.

1) Layered Architecture: The protocol stack in wireless sensor network is an hybrid model between OSI and TCP/IP model as shown in Figure 1.

We are interested to present the layers that will be used in our work. The physical layer is responsible for frequency generation, modulation, and data encryption. The two sublayers of Data link layer are DLC (Data Link Control) which is responsible of multiplexing and error control, and

MAC (Medium Access Control) which is responsible for Channel access and scheduling. The primary function of network layer is routing. More detailed description can be found in (6).

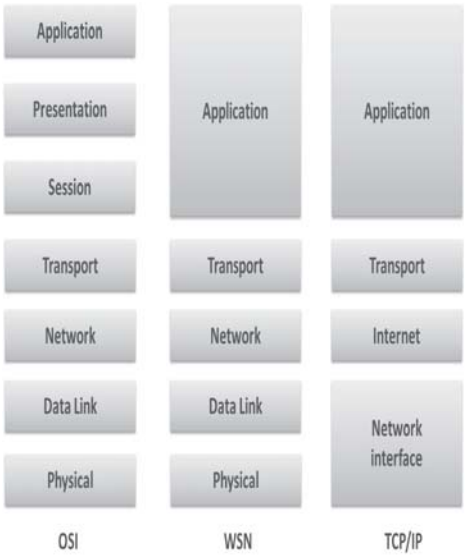

Fig. 1. Comparison of Similar Layer Models.

2) Cross Layer Design Overview: In presented layered architecture in Figure 2, each layer has its own functionality and can use only the services provided by the layer below it. So, the communication is permitted only between adjacent layers. On the other side, in the cross layer approach, each layer can use services provided by any other layer. The interactions between all layers of the network protocol stack improve performance of WSN. Different cross-layer designs have been classified into six approaches in terms of possible interactions between physical (PHY), medium access control (MAC), Routing (NET), and application layers (APP).

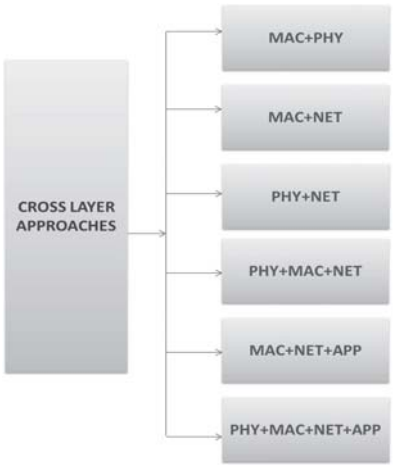

Fig. 2. Cross Layer Approaches.

3) MAC + PHY LAYERS: Cross-layer approaches which use interaction between physical and MAC layers are presented to achieve energy efficiency.

A cross layer design for multichannel non persistent CSMA is presented in (8). The method combines adaptive modulation and band width partitioning at the physical layer and adaptive back off at the MAC layer. The energy efficiency is provided in this work but faces many difficulties due to some complexity constraints presented on the WSN nodes.

The work reported in (10) presented a mechanism that simplify energy conservation for WSN. A physical layer model is used to check the effectiveness of the cross layer optimization done by adding multiple access interference as a new parameter in the model (star topology). So, the CLPC algorithm minimizes the overall energy consumption in the network by decreasing the transmit power between the nodes and cluster head. The disadvantage of this technique is that the implementation has meaning only when it is performed in fewer numbers of nodes.

4) MAC + NET LAYERS: Cross-layer approaches which use Interaction between MAC and Network are used to jointly build a scheduling and routing mechanism in the WSN.

The work reported in (2) proposed an integer linear program (ILP) model for energy efficient distributed schedule based (EEDS) protocol to provide the increased network life time. This model is verified through different numerical examples and these results have been combined with EEDS which is the best method to jointly build a routing and schedule for WSN.

The work reported in (3) presents a cross layer protocol called MERLIN (MAC and efficient routing integrated with support for localization) that integrates MAC and routing functionality. It employed a multicast upstream and downstream method to rely packets to and from the gateway to increase the network lifetime with less latency.

In the work reported in (5) a cross layer protocol which replaces the entire traditional protocol architecture is

developed, both the information and the functionalities of communication layers are combined in a single protocol.
The work described in (4) proposed an iteration algorithm to solve the mixed integer convex optimization problem. In their work, the authors discuss a power controlled MAC called cross layer power alternative MAC (CL-MAC).

5) PHY + NET LAYERS: Various cross layer approaches are presented which is formulated by using interaction among physical and network layers that can reduce many problems in wireless sensor networks such as bandwidth, load balancing, routing and congestion.
The work reported in (13) formulates a cross layer protocol for obtaining a trade-off between the energy and throughput to solve routing and bandwidth allocation problem, they included a parameter called network utility in the framework for traffic flow assignment and routing tree construction.
A cross-layer optimization is presented in the work reported in (14) to improve network throughput for multi hop wireless networks. They treat multi-hop flow routing and power allocation at the physical and network layer.

6) PHY + MAC + NET LAYERS: Different cross layer protocols which use interaction between physical, MAC and network layer are presented to improve energy efficiency, reliability and throughput on WSN.
The work described in (3) proposed an energy optimization protocol based on physical, MAC and routing as a cross layer for WSN named EOA which computes the optimal transmission power routing and duty cycle schedule that increases the WSN energy efficiency. Considering transmission power as a metric the routing protocol selects the appropriate route for forwarding packets and it is used to form a duty cycle schedule in MAC layer.
A Cross Layer Energy Efficient Routing Protocol named XLE2R proposed in the work reported in (10) gives cross layer interactions between PHY, MAC and the Network Layer. XLE2R is divided into three phases: route finding, route maintenance and route re-establishment.
In the work described in(11), the optimization of transmission power, transmission rate, and link schedule for TDMA-based WSNs is proposed and performed to maximize the network lifetime.
The authors in (7) proposed a cross layer scheme for routing mechanism named CLB (Cost Link Based) to improve network lifetime by efficiently routing the traffic inside the WSN. CLB uses multiple paths between sensor node and sink node, thereby balances the traffic inside wireless sensor network. Based on network topology, link distance can be calculated and link cost highly depends on cross layer design that neglects the paths with nodes, having limited energy than specified threshold.

7) MAC + NET + APP LAYERS: In the work reported in(12), the authors proposed a cross layer protocol between MAC, Network and Application Layers to avoid congestion and improve a reliability in WSN. They discussed a congestion mitigation scheme by sending feedback by the MAC layer to the network layer. So, the traffic generation rate is balanced by application layer.

8) PHY + MAC + NET + APP LAYERS: In the work described in (9), the authors used a cross layer protocol between Physical, MAC, Network and Application Layers for cognitive radio communication based on distributed control algorithm to reduce the effects of the propagation conditions in power system. So, on demand routing action data scheduling is also formulated to ensure the data delivery in the network and a flow control is used in this work.
The energy management is an important issue in WSN, the goal of this paper is to minimize the power consumption and to adopt cost-effectiveness tests for energy efficiency. So, according to the work reported in (1) which reviewed various cross layer design protocols, the literature exposed that MAC layer is a common part in most of the design and also MAC-Routing schemes provide better results in terms of energy management. As well, cross layer interaction provides good performance than the single layer protocol stack.
In our work we used an improved routing algorithm based on LEACH Protocol. For more details about LEACH Protocol you can see (16). Before we outline the power consumption requirements and present our cross layer method, we need to define some preliminaries and concepts.

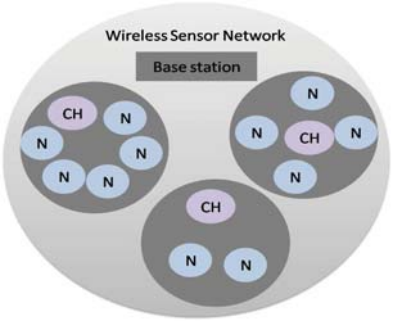

Fig. 3. Energy Adaptive Clustering Hierarchy Protocol.

9) LEACH Protocol Overview: LEACH - Low Energy Adaptive Clustering Hierarchy: As shown in Figure 3, LEACH Protocol is an hierarchical clustering-based routing protocol. It is self-organizing and adaptive clustering. LEACH utilizes randomized rotation of local cluster base stations (cluster-heads) to evenly distribute the energy load among the sensors in the network, operations are broken into rounds, each round is made on two phases: Setup Phase and Steady Phase.

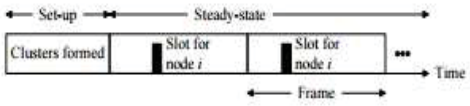

Fig. 4. LEACH Protocol Process.

LEACH protocol process is shown in Figure 4
At the first stage (clusters formed), the decision to be cluster-head is made by node i choosing a random number between 0 and 1.
$If value < t(n)$, node becomes cluster-head; this number to the threshold values t(n), if the number is less than t(n), then it becomes cluster head in this round, else it becomes common node.
Threshold t(n) is determined by the following equation:

$$t(n) = \begin{cases} \frac{p}{1-p*(r \bmod \frac{1}{p})} & if \quad n \in G, \\ 0 & if \quad n \notin G. \end{cases}$$

Parameter	Description
t(n)	threshold
P	desired percentage of cluster head node
r	current round
G	set of nodes not cluster head in 1/P rounds

TABLE I
DESCRIPTION OF LEACH PARAMETERS

- Using this threshold, each node will be a cluster head in 1/P rounds;
- Nodes that are cluster-heads in round 0 can't be again for next 1/P rounds;
- After 1/P -1, T=1 and 1/P rounds, all nodes are eligible again to become cluster-heads;
- After 1/P-1 round, all nodes which have not been head nodes will be selected as head nodes with probability 1;
- When 1/P rounds finished, all nodes will return to the same starting line.

Setup Phase

Each node that elected itself a cluster-head for current round as explained in the first stage (clusters formed), broadcasts advertisement message to the rest of nodes.
They use a CSMA MAC protocol: All cluster-heads transmit advertisement using the same transmit energy.
Non-cluster-head nodes must keep receivers on during this phase to hear advertisements.

Steady Phase

- After node picks cluster, it must inform cluster-head using CSMA MAC protocol again;
- Cluster-head then creates a TDMA schedule telling each node when it can transmit (broadcast back to nodes in cluster, probably using CSMA);
- Allows radio components of each non-cluster-head node to be turned off during its transmit time, thus minimizing energy dissipated in individual sensors;
- In this step, Cluster-head has all data from the nodes in its cluster, aggregates data and transmits to base station;
- When nodes pick cluster, all cluster-head nodes must keep receivers on.

B. Hybrid Spread Spectrum Approach

Telecommunications with spread spectrum are a radio transmission technique where the signal is transmitted over a greater spectral width that the bandwidth of the original signal when it was transmitted by conventional modulation methods. The spread spectrum is a transmission technique of spreading the energy of a telecommunication signal over a bandwidth which is much greater than the information rate. In the work reported in (15), the originality of this hybrid approach compared to others spread spectrum methods is that can remedy the insufficiency of FHSS by combining it with THSS to reduce the energy consumption. So we used this method for scheduling on our cross layer approach to evaluate the cost effectiveness and energy efficiency in WSN by a simulation in two WSN platforms. Figure 5 explained in more details this approach.

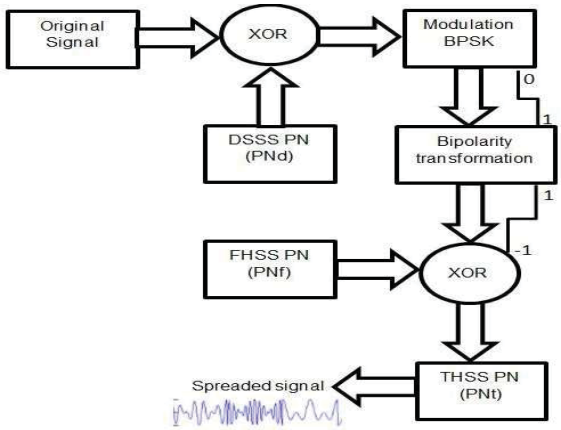

Fig. 5. Hybrid Spread Spectrum Approach.

CONTRIBUTION In this section, we will describe our proposed cross layer approach and we will give its formalization to be more clear.

1) Description: The cross-layer approach proposed in this paper preserves traditional layered structure and considers the interaction between (Physical, Mac and Network) protocol layers. So, the mechanisms of each layer still stay intact, while each layer is informed about the conditions of other layers. Our protocol named (PCP-PMN: Power Consumption Protocol-Physical, Mac and Network) uses the cross-layer Wireless

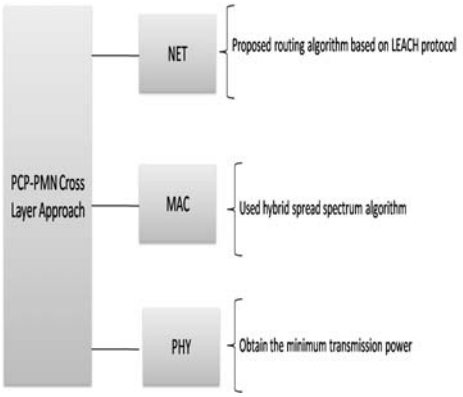

Fig. 6. Major Parts of our PCP-PMN Contribution.

Sensor Networks which uses three layers (Physical, Mac and Network) to treat the cost effectiveness and energy efficiency.

Figure 6 shows the major parts of our contribution; our first idea is to treat transmission power parameter because the communication energy represents the largest portion of the energy consumed by a sensor node. When the transmission power is high, the energy consumed will be higher, so:

1) At the physical layer: PCP-PMN obtains the minimum transmission power that requires minimum communication energy and gives this node a higher priority.

2) At the network layer: PCP-PMN proposed the routing algorithm based on LEACH protocol to choose the optimal path by using the parameter obtained at the physical layer.
   The decision to be cluster-head is made by choosing the node that requires the minimum power transmission obtained at the physical layer.
   For the next round, obtaining the minimum power transmission to be elected as a cluster-head.

3) At the mac layer: PCP-PMN used hybrid spread spectrum algorithm to treat transmission power, transmission rate and link schedule to maximize the network life.
   In the scheduling phase, nodes use proposed hybrid spread spectrum to palliate the weaknesses of Time Division Multiple Access (TDMA).
   Our cross layer approach between PHY, MAC and NET layers built a scheduling and routing mechanism in the WSN by using proposed network protocol based on LEACH and hybrid spread spectrum protocol to achieve the energy efficiency.

The details for the ordered parts of PCP-PMN construction are described via pseudo code as follow:

The notation used in the pseudo code
S_alive: set of alive nodes in the WSN
Tx: transmission power
CH: cluster head
S_Non_CH: set of non cluster head nodes

```
1  begin
2  For every node in S_alive do
3  If (Tx == Smaller)) then
4  Min_Power ← Tx
5  Node_i ← Max_Priority
6  CH ← Node_i
7  CH send DS-FH-THSS slots to S_Non_CH
8  S_Non_CH send data to CH
9  Sleep_Mode (S_Non_CH)
10 CH aggregate data
11 CH send data to BS
12 EndIf
13 EndFor
14 end
```

Fig. 7. Major Parts Of PCP-PMN Pseudo Code.

Figure 7 shows the pseudo code of major parts of PCP-PMN.

Throughout implementation, we calculate the run time complexity of PCP-PMN algorithm executed on two WSN platforms (TinyOS and Contiki OS).

In this step, we evaluate the number of instructions. However, tinyOS integrates a component-based architecture that reduces the number of instructions what makes minimizing the execution time compared to contiki. Thus, on Contiki platform PCP-PMN algorithm is more complex and consumes more power. Our approach performs an optimization in order to reduce the power consumption but TinyOS is more efficient in terms of total run time complexity compared to Contiki.

C. Experimentation and Discussion

Implementation of cross layer PCP-PMN algorithm
Simulation with PowerTOSSIM
Simulation with COOJA
Comparative analysis

Fig. 8. Experimentation Steps.

Figure 8 shows the steps of the implementation process of our proposed work. In this experiment, we implement our PCP-PMN (Power Consumption Protocol-Physical, Mac and Network) based on cross-layer for WSNs which uses three layers (Physical, Mac and Network). We consider an example of WSN simulation and implemented our approach by using COOJA (18) and PowerTOSSIM simulator tool (17) which simulates the behavior of WSN and we compare the results of the energy estimation obtained through simulation between two platfroms.

1) Experimentation Results: Firstly, at the physical layer we aim to obtain the minimum transmission power and giving this node a higher priority.
Secondly, at the network layer, we used this parameter as a metric to make improvement of the proposed routing algorithm based on LEACH protocol.
Thirdly, at the mac layer, making scheduling by using the proposed hybrid spread spectrum.
Finally, we simulated by running our PCP-PMN algorithm, evaluated and compared the results of the estimated energy obtained through the simulation between the two WSN platforms (PowerTOSSIM a TinyOS simulator and Contiki OS the COOJA Simulator).

	Initial power consumption	Power consumption with PCP-PMN
TinyOS	0.147000003	0.116000003
ContikiOS	0.134000006	0.123000002

Fig. 9. Power Consumption Measures.

In initial state, before applying the PCP-PMN, we oberve the initial power consumption as shown in Figure 9.
During the execution of the PCP-PMN, the consumption goes down.
Figure 9 shows a comparison between the obtained values for the two experiments.
We can show that there is a difference in the energy spent before and after applying our PCP-PMN algorithm and there is a difference between the two results.
The difference of the efficient energy is approximately 0.031 W.
The implementation of PCP-PMN in PowerTOSSIM a TinyOS simulator preserves more energy and leads to a better performance system in terms of complexity compared to Contiki OS the COOJA Simulator.

III. Conclusion

This paper work presents a Power Consumption Protocol-Physical, Mac and Network (PCP-PMN) based on cross-layer for Wireless Sensor Networks which uses three layers (Physical, Mac and Network) with the aim to study the energy consumption.
Energy efficiency is the major factor that determines the lifetime of WSNs.
The main contribution of our work, an energy optimization approach for wireless sensor networks is present, named PCP-PMN based on a Cross-layer approach between physical, MAC and Network layer. PCP-PMN obtains at the physical layer the minimum transmission power and gives this node a higher priority. Then used this parameter as a metric to make improvement of proposed routing algorithm based on LEACH protocol at the network layer and to perform scheduling by using proposed hybrid spread spectrum at the mac layer.

Our algorithm improves reliability of communications, saves energy and uses bandwidth more efficiently.
The implementation of PCP-PMN in PowerTOSSIM a TinyOS simulator preserves more energy and leads to a better performance system in terms of complexity compared to Contiki OS the COOJA Simulator. Further work is oriented to test and evaluate in real WSN by using cross layer approach.

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