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APEEJAY JOURNAL OF COMPUTER SCIENCE AND APPLICATIONS

ISSN:0974-5742(P)
Vol. 1, January 2013

Cross Layer Energy Efficient Protocols for Wireless Sensor Networks: A Survey

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ABSTRACT

Wireless Sensor Network (WSN) consists of large number of sensor nodes having limited battery power. Developing energy efficiency protocols to optimize the energy consumption is most important for lifetime and survivability of WSNs. Energy consumption optimization is required at all the layers of protocol stack but, most work focus only on optimizing single layer in terms of energy consumption for WSNs. We propose a cross layer energy efficient protocol which optimizes energy consumption of the sensor nodes at the Network, MAC and Physical layers of the protocol stack as most of energy consuming factors exist in these three layers. This paper also consider multi hop transmission in WSNs since transmitting data through multiple hops from source to sink consumes less energy as compared to transmitting data directly to sink in a single hop.

Keywords: *Wireless Sensor Networks, Cross Layer, Energy Efficient protocols.*

1. Introduction

A Wireless Sensor Network (WSN) is a self-organizing wireless network consisting of large number of sensor nodes distributed over the area of interest. Each sensor node is tiny, lightweight, and portable. A sensor node in a WSN is typically equipped with a transducer, a radio transceiver, a small microcontroller, and a power source (usually batteries). The transducer can convert sensed physical effects and phenomena into electrical signals. Consequently, sensor nodes can cooperatively monitor physical or environmental conditions to collect, record, and report data and information of monitored objects. Generally, monitored parameters are temperature, humidity, wind direction, speed, illumination intensity, sound intensity, vibration intensity, pressure, power-line voltage, chemical concentrations, motion, pollutant levels, and vital body functions. The microcontroller processes and stores the sensed data. The radio transceiver is responsible for receiving and sending data packets from/to other sensor nodes and to sink node. Also, each sensor supports a multi-hop routing algorithm, so a packet can be received by the destination node through multi-hop forwarding. Initially, WSNs were designed for military applications such as battlefield surveillance. But, nowadays WSNs are widely used in many civilian and industrial application areas, such as industrial process monitoring and control, machine health monitoring, robot control, environmental monitoring, habitat monitoring, healthcare applications, home automation, object tracking, detecting disasters, and traffic control. In most applications, WSNs are required to be operating in order to months to years but constituent sensor nodes have limited battery power. Therefore, survivability is one of the critical issues and the most important research factor in the field of wireless sensor networks (WSNs) [1]. Hence, energy efficiency is most important criteria for survivability and lifetime of WSNs. Therefore, developing approach to optimize the energy consumption has been a major consideration in WSNs. The major sources of energy waste [2] in WSNs are the following:

Collisions: When two nodes simultaneously try to transmit data, the transmitted packets gets corrupted, they has to be discarded, and the follow-on retransmissions increase energy consumption.

Control Packet Overhead: Sending and receiving control packets consumes energy too, and less useful data packets can be transmitted.

Idle Listening: listening to receive possible traffic that is not sent.

Overhearing: a node picks up packets that are destined to other nodes.

High Transmission Power: Unnecessarily high transmission power leads to energy wastage.Traditionally, the problem of energy consumption optimization is considered separately at different layers of the protocol stack. At Network Layer, inefficient routing of packets can lead to waste of energy. A protocol that needs many routing advertisements will make use of sensors energy to send them, reducing the network lifetime [3]. Thus energy efficient routing protocols can help to reduce energy consumption by avoiding retransmissions and less control packets. At Data Link Layer, error control techniques are necessary as wireless links are not reliable. In order to avoid collisions, WSNs should use contention less medium access and coordinated sleep schedules [4]. But all these solutions are energy consuming, since the techniques to solve them require resources from one or more nodes. Thus, every proposed solution needs to be energy efficient.

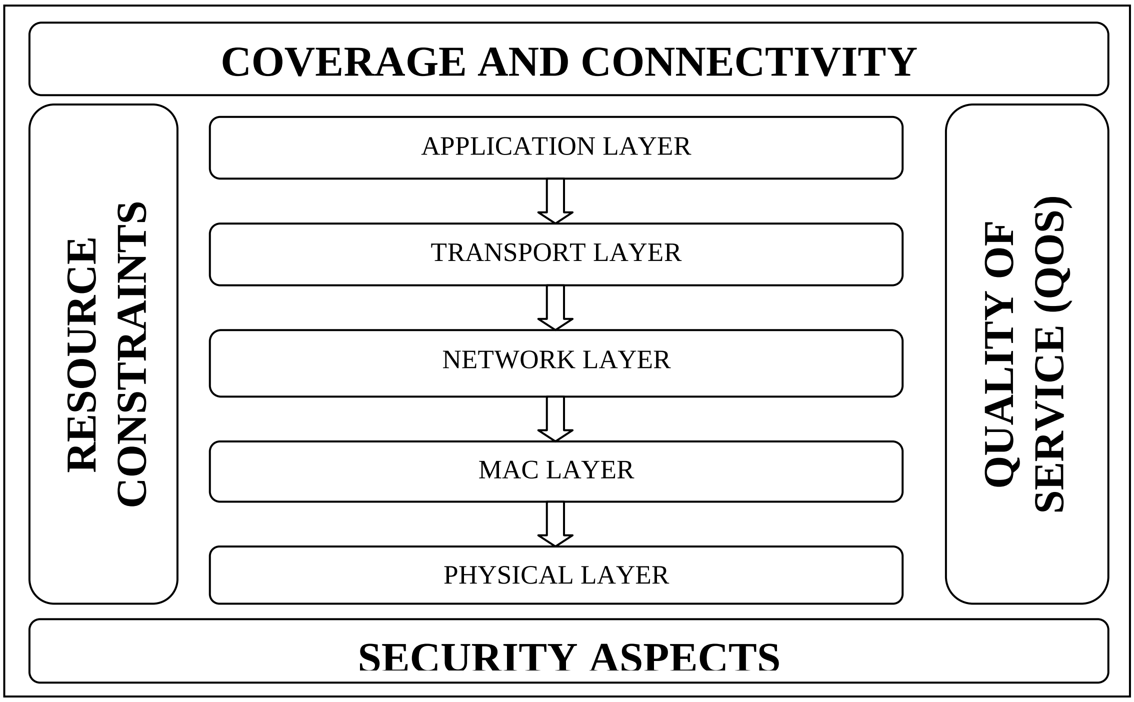

Fig 1: Cross Layer Issues in WSNs

At Physical layer, transmission power is to be optimized in order to have energy efficient routing protocol since most of the energy efficient routing protocols assign link cost as some function of transmission power which further depends upon several metrics like path loss, Signal to Interference plus Noise Ratio (SINR), Bit Error Rate (BER) etc. Even though a vast variety of single layer energy efficient solutions exist for different layers of protocol stack, but none of the single layer solution can optimize energy consumption well, as energy consuming factors are distributed across the layers of the protocol stack. A comprehensive, cross layered scheme of energy efficiency solutions seems to be the best approach to cope with the problem of energy efficiency as depicted in Fig 1 [5]. Cross-layer design states that parameters of two or more layers can be retrieved and/or changed in order to achieve an optimization objective [6]. Cross-layering is still in its early development in this type of networks since it has not been deployed on many networks yet. However, different solutions which have already been proposed, and at least in simulations, they have proven to achieve better performance gains than their single layered counterparts [7]. Since most of the energy consuming factors exist in the first three layers of the protocol stack, therefore we limit our research to the Network, MAC and Physical layer aspects.

2. Related Work

A few cross-layer protocols have been proposed for WSNs in literature. These cross-layer protocols jointly optimize the different layers among physical (PHY), medium access control (MAC), Network (Routing) and Transport layers. In [1], authors proposed an Energy Optimization Approach named as EOA based on Cross-Layer for Wireless Sensor Networks, which considered the joint optimal design of the physical, medium access control (MAC), and routing layer. In the physical layer, EOA controls transmission power dynamically and obtains the proper transmission power level between two nodes. In the meanwhile, each node maintains a neighbor table to record this proper transmission power level. Then each node in the network layer constructs its routing table by utilizing the neighbor table of the physical layer. Finally, EOA uses the cross-layer routing information to determine the duty-cycle of each node, and meanwhile EOA also pays attentions to collision and overhearing problem in the MAC layer. In [6], authors gathered and discussed most of the recent research in the field. Paper has shown that there are different categories of WSNs, and that each of them has their own set of problems to be addressed. Furthermore, well-known problems have been discussed and some available cross-layer solutions have been briefly presented. Then, the layers and used technologies have been discussed, also presenting cross-layer approaches that are examples of the used technologies. Finally, concluded that there is still much to be done in order to achieve a comprehensive cross layer design that addresses the issues at every layer of the stack in an energy-efficient manner. In [8], authors proposed a cross-layer medium access control/routing protocol called RSSI-based Forwarding (RBF), which was based on a Received Signal Strength Indicator (RSSI) as a routing parameter for multi-hop WSN. In this protocol, the next-hop node for data-forwarding task is determined without using prior knowledge of nodes geographical locations and without maintaining neighborhood routing tables. For an arriving beacon signal transmitted by the sink, received power levels are computed for each sensor node in the network and these levels are then used as a decision parameter for the nodes to contend for the forwarding task of the data packets .In [9], authors presented a cross layer design approach with the concept of cooperation among the nodes with best farthest neighbor scheme. In this paper, the information about wireless medium of physical layer and MAC sub layer is passed to the network layer and the information of network is transmitted to lower layers. Information about the physical channel condition is transmitted from physical layer to network layer. Data rate and power information were transmitted from network layer down to the physical interface. In [10], authors proposed a unified cross-layer framework that includes connection admission control together with QoS routing in the network layer and distributed opportunistic proportional fair scheduling in MAC layer. A novel utility function is defined which is exchanged between an efficient distributed opportunistic proportional fair scheduler and a multi-constrained QoS routing algorithm. Furthermore, a novel tightly-coupled design method for joint routing and admission control has been demonstrated, where a unified optimization criterion “QoS performance index" combine multiple QoS constraints to indicate the QoS experience of each proposed route. In [11], authors considered the joint optimal design of the physical, medium access control (MAC), and routing layers to maximize the lifetime of energy-constrained wireless sensor networks. The problem of computing lifetime-optimal routing flow, link schedule, and link transmission powers for all active time slots is formulated as a non-linear optimization problem. The link schedules were restricted to the class of interference-free time division multiple access (TDMA) schedules. In this special case, the optimization problem was formulated as a mixed integer-convex program, which can be solved using standard techniques. Moreover, when the slots lengths were variable, the optimization problem is convex and can be solved efficiently and exactly using interior point methods. For general non-orthogonal link schedules, an iterative algorithm was proposed that alternates between adaptive link scheduling and computation of optimal link rates and transmission powers for a fixed link schedule. In [12], authors performed the routing decision as a result of successive competitions at the medium access level. The next hop is selected based on a weighted progress factor and the transmit power is increased successively until the most efficient node is found. Moreover, on-off scheduled are used. The performance evaluations of all these propositions present the advantages of cross-layer approach at the routing and MAC layer. These above works provide analytical and simulation results without any communication protocol design and performed cross-layer design within limited scope, which do not consider all of the layers of the protocol stack involving in the communication in WSN, such as routing, medium access and physical layers. Thus, there is a need of comprehensive cross layer energy efficient protocol design.

3. Proposed Cross Layer Protocol

Cross-layer approach mentioned above considers the interaction between corresponding protocol layers, and preserves the traditional layered structure.Each layer is informed about the conditions of other layers, while the mechanisms of each layer still stay intact. Guided by above cross-layer principle, we design our cross-layer energy efficient protocol as in Fig.2. Firstly at physical layer, the protocol calculates the path loss based upon RSSI by means of beacon packet transmission from a sink node. Using path loss, a node decides whether or not to participate in contention to be a relay node. Secondly at network layer, a node with larger RSSI value (or with a shorter path loss as compare to the sender) is selected for the data forwarding task as next-hop node. Thirdly at MAC layer we form the sleep/listen scheduling scheme for each sensor node. By this scheme, a node must be awake if and only if it takes part in the actual transmission activity; otherwise it continues to keep asleep in the rest of time. Finally again at physical layer, this algorithm obtains the threshold transmission power level between the transmitting node and selected next hop node and data transmission takes place with minimum transmission power level just above the threshold transmission power level.

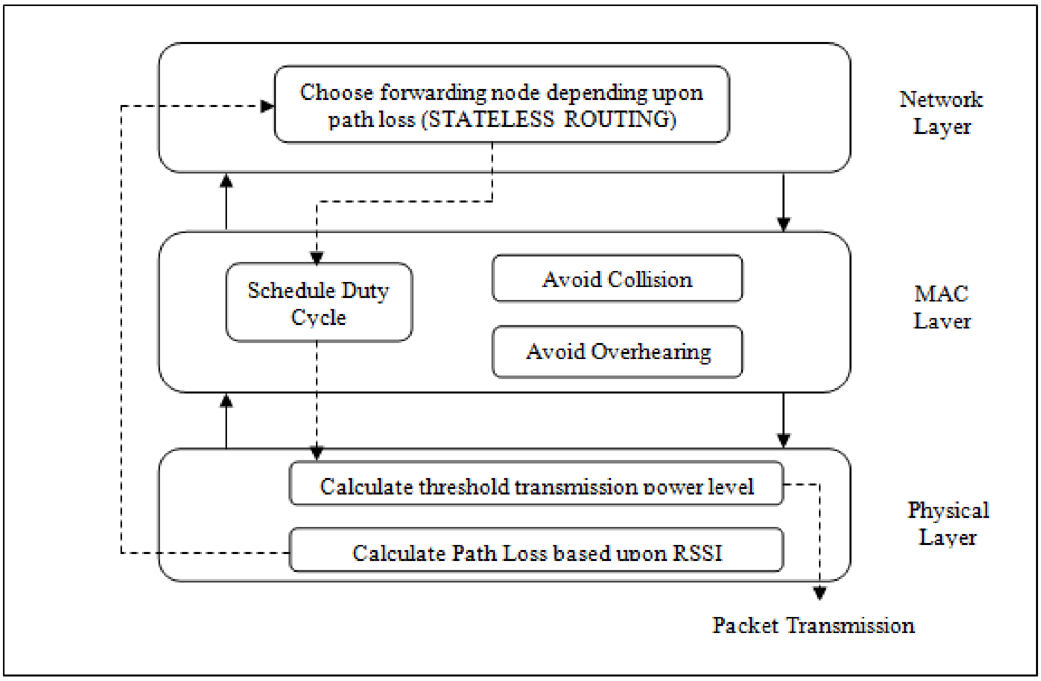

Fig 2: Cross Layer design of the Protocol

4. Conclusion and Future Work

In this paper, we have proposed a cross layer energy efficient protocol for Wireless Sensor Networks which optimizes energy consumption at the lower three layers of the protocol stack. In future, we will model this protocol in one of the simulation modeling tools like OPNET, MATLAB to verify the proposed protocol and then validate the results by comparing them with the results of the existing protocols. With results validation, we can conclude that the optimization of energy consumption using cross layer approach is better than the single layer approach. In future, we would also like to include upper layers of the protocol stack in the cross layer structure of the energy efficient protocol for the multi hop Wireless sensor networks.

Acknowledgement

This work was completed in part with resources provided by the Punjab Technical University, Jalandhar. The authors gratefully acknowledge the support of Punjab Technical University, Jalandhar for of this work.

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