International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 24 (2017) pp. 14755-14759

A proposed Analytical Model for Integrated Multiple Layers of OSI for Energy Utilization in WSN

Urmila Patil[1], Anju V. Kulkarni[2] and Radhika Menon[3]

Research Scholar[1], Professor[2], [3]Professor
[1,2], Department of Electronics and Telecommunication, Dr. D. Y. Patil Institute of Technology, Pimpri, Pune, Savitribai Phule Pune University, Maharashtra, India.
[1]Orcid Id: 0000-0002-7080-0834, [2]Orcid Id: 0000-0002-3160-0450

[3]Department of Mathematics, Dr. D. Y. Patil Institute of Technology, Pimpri, Pune, Savitribai Phule Pune University, Maharashtra, India.
Orcid Id: 0000-0002-0389-9037

Abstract

WSN has become a technology that promises a wide variety of applications from agriculture to health care. WSN intends to capture a certain incident (activity- data) and sends the data to sink using a single –hop / multi - hop network. Energy is a critical issue for sensor life time. To augment the lifespan of the sensing node's battery, curtailing the energy utilized in various constituents like the listening activity, sensor log-in and actuation (sensing process), routing and communication (transmission and reception) becomes vital. In this paper, a unique approach focused on integrating the physical layer and data link layer is proposed. This model not only focuses on energy utilizing/consuming constituents (activities) carried out by sensors and other circuitry such as transceivers and processing units, but also takes into cognizance the environment (path loss) and network parameter (traffic density) of an entire sensor network application. This approach is to construct an energy utilization model of a generic WSN application and establish the relationships between these components so that optimizing the overall energy utilization of the complete application can be explored as an energy management model thereby enhancing the network life time to be implemented in real time systems.

Keywords: Integrated Energy Utilization Models, Wireless Sensor Networks, Clustered Energy Consumption (CEC), Ad hoc Networks, Coordinator (Sink), Traffic Density, Path loss.

INTRODUCTION

The area of wireless sensor networks (WSN) has become a focus of exhaustive research in recent years and gaining popularity as one of the most important technologies due to the possibility of blending these devices with their environs. The scope of extensive research in wireless sensor networks (WSNs) has opened up new and interesting opportunities in the fields of robotics and automation.

The sensor networks have moved from fixed location computing to on-site environment computing (ambient computing) due to which there is a paradigm shift from the user-driven model to an event-driven model.

Development of pervasive systems that can collaborate with each other to exchange information regarding the physical environment around them, prevent disasters, robustness and operation without any human involvement is the result of WSNs [1].

WSN basically consists of thousands of interconnected sensor nodes that are spatially distributed (to monitor their physical environment), microcontrollers and electronic circuitry (for processing the sensed data), antennas (for send/receive the processed data between the sensing nodes, Coordinator (base station, sink)), and Battery (for energy source or energy harvesting: solar energy). The topologies that WSNs can have are star, tree, single hop to advanced multi-hop wireless mesh network. Distribution of nodes in the surroundings can be structural or non-structural. In the structural network, the location of each node (both sensing and coordinator) is clearly known. In non – structural, the nodes after distribution cannot be modified or controlled, and their only function is to monitor the environment (parameter), process the data and build the network by finding and connecting to their neighbors.

Quality of WSNs is assessed using several metrics. Major ones are the Network Lifetime (LT) [1], Energy Efficiency (EE) [2] which aimed to reduce the amount of energy usage for a given task, Routing, End-to-End latency which refers to the time taken for a packet to be transmitted across a network from source to destination [4], and Expected Data Rate (EDR) that captures the effect of per-hop contention and multi-hop throughput [5].

Moreover, Sensing nodes are generally deployed in non-accessible environment; therefore, reaching and changing of sensing nodes is not feasible. Hence, they totally are dependent on the battery for all operations and rely on energy harvesting (e.g., solar cells) for recharging. Therefore, the biggest challenge, in WSNs is conserving energy and extending the lifetime of the battery and hence of the network. Some of the other constraints associated with the operation of wireless sensor networks are: node breakdown, mobility of nodes, communication malfunction, size and cost constraints on sensor nodes. These in turn adversely affect the resources such as energy, memory, computational speed and communication bandwidth.

In this research paper, network lifetime is defined as "The maximal time up to (till the time) which the desired throughput cannot be achieved" where the parameters considered to define the network performance are: Energy consumption in communication, Routing and Data rate. Integrated approach of defining an energy consumption model is presented in this paper which takes into consideration various energy consuming components from different levels of the OSI model. This eases the task of minimizing or optimizing the energy levels of the network leading to power management in WSN.

System Model

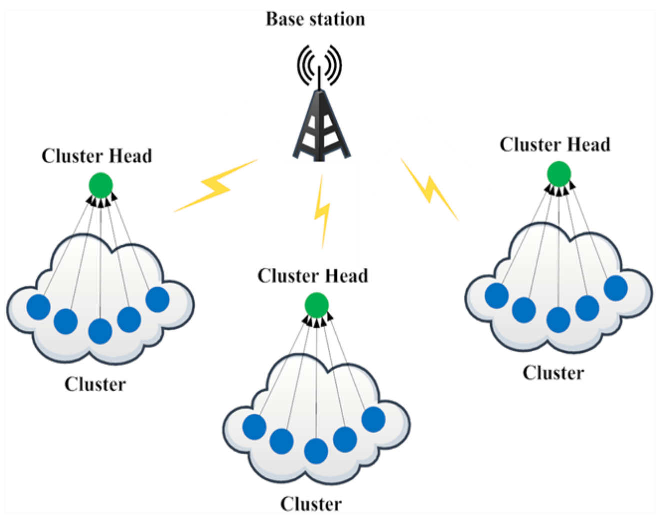

Figure 1: WSN Architecture

The energy utilization model is defined as developing mathematical expressions of a WSN and analyzing the same varying the parameter of the network. The performance of the energy utilization model is a function of these system parameters. The parameters are defined as initial values during design time, (e.g., Initial energy), and they can be modified in due course after a system has been put into operation (e.g., Packet sizes and transmitted power) [7]. Many endeavors to model energy utilization for sensor nodes can be seen in literature. These models have been basically categorized into three types via Physical layer energy models, MAC layer energy models and Cross-layer energy models.

Energy Utilization models have considered the parameters listed in Table 1 below. (As in literature)

Table 1: Parameters for Energy Utilization Model

Models	Sources of energy consumption (Parameters)	Parameters considered for the models
Physical Layer	Hardware of WSN node (sensor, processor, transceiver and power unit), wireless channel error, modulation scheme and physical layer overhead.	• The power transmitted: It is the utilization of energy every second, which is observed while transmitting one element of information from nodule a to nodule b. • The power received: It is the utilization of energy every second, which is observed while receiving one element of information from nodule a to nodule b. • The detecting energy: It is the utilization of energy for detecting the presence of one bit. • Overhead across the physical layer: The presence of repeated bits which are present in the packets across the physical layer. • Power associated with sleeping: This is the power which goes waste when the nodes of the sensors switch off all the components. • Power linked with transients: The amount of power which goes in waste when there is no alteration in the modes of operation. • Problems of overhearing: This happens when the nodule gets packets which are present in the shared network. These packets are actually for some other receiver and they accidentally receive them and is not meant for the receiver which has received it. • Problems associated with collision: This happens in conditions when two nodules are sending information or data at the same period of time. • Overheads present across MAC layer: This mainly relies on the kind of MAC protocol which is being used. • Data Rate of the link: The average movement of traffic from nodule a to nodule b is the data rate associated with the link.
MAC Layer	Type of MAC protocol (Schedule based or Contention based), overhead of MAC protocol, overhearing and collision.	
Cross layer	Energy consumption at various communication layers.	

Problem statement

We assume

- Cluster-based energy consumption model (CEC) : In this paper, a fixed environment is considered, therefore a Cluster-based energy consumption model (CEC) CEC model is assumed since (CEC) consumes minimum energy

- Homogenous sensor networks: All nodes are of the same type and have equal routing tasks assigned to them.
- Time-synchronized: In cluster-based protocols, Coordinator (cluster head) performs the role of accumulator and compiler (to compress data, compile data and perform in-network processing). Accumulating and compiling data from different nodes or in general aggregating demands the WSNs to be time-synchronized.
- Integrated approach: All layers of the OSI network model are considered with the sole purpose that this can be used for reducing the total energy utilization of the complete network used for the application.
- This approach focuses on energy components (tasks, activities) performed by sensors and its counterparts such as sensors, transceivers and processing units, environment such as path loss and network parameter such as traffic density of an entire sensor network application. This approach is to develop an energy utilization model of a generic WSN application and establish the relationship between these components so that optimizing the overall energy utilization of the whole application can be explored as an energy management model for enhancing the network lifetime to be implemented in real time systems.

Mathematical Model

The analytical model designed for integrated approach for energy utilization in WSN is modeled using graph theory. The entire network is treated as a directed graph as given below Notations:

- G = (V; L), where V represents the vertices comprising of N sensing nodes and one coordinator, and L denotes the directed link set; (i, j) ∈ L implies the link between sensor node i to sensor node j over which that data can be transmitted.
- xij is routing variable that is associated to each sensor node i such that link (i, j) ∈ L.
- xij > 0 : message is sent from sensor node i to sensor node j over the link (i, j)
- xij = 0 : Transmission does not occur on the link (i, j)

Generalized Integrated model for the energy consumption per bit 'Eb' is

$$E_b = E_{@trans} + E_{@rcr} + E_{transm} \qquad (1)$$

- E@trans: Term that relates to the energy utilized (expended on) per bit of data for over-heads of transmitter electronics (actuators, oscillators, amplifiers, filters, PLLs etc.)
- E@rcr: Term that relates to the energy utilized (expended on) per bit of data for the overhead of the receiver electronics (actuators, oscillators, amplifiers, filters, PLLs etc.)
- Etransm: Term that is distance dependent and relates to the energy utilized (expended on) per bit of data by the transmitted data to travel a particular distance ' d', path-loss component, traffic density in the defined link.

$$E_{transm} = \sum_{i,j\in S} Z_{ji}(p_{ij}^{TX} R_{ij}) + \sum_{i,j\in S} Z_{ji}(p_{ji}^{RX} R_{ij}) + \sum_{i,j\in S} k \times d_{ij}{}^{\gamma} + P_{TD} \quad (2)$$

Where,

- R_{ij} is the Transmission rate (average traffic flow (bits per second)) on a link (i, j)
- d_{ij} : distance for link (i, j)
- Z_{ji} is the pointer function stating whether the node belongs to link (i; j).
- Z_{ji} = 1, if node belongs to link (i, j)
- Z_{ji} = 0, if node does not belong to link (i, j)
- k is a coefficient of path loss defined by the type of the environment of communication
- ɣ is the term for path-loss component
- P^{TD} is power dissipated due to traffic density
- P^{TX} is the power utilized for transmitting per bit of data
- P^{RX} is the power utilized for receiving per bit of data

The Path loss is an important aspect in estimating the energy utilization at a node.

For the current research work, the standard log-distance path loss model is used:

$$PL = P_{TX[dBm]} - P_{RX[dBm]} = PL_0 + 10\gamma \log_{10} \frac{d}{d_o} + X_g \qquad (3)$$

Where

- PL: Loss in the path in ideal condition which is indicated in dB.
- P_{TX}[dBm] : Power transmitted
- P_{RX}[dBm]: Power received
- PL_0 : path loss at a reference distance d0 (usually 1km)
- 'γ' : path loss exponent
- 'd' : length associated with the path
- 'X_g': attenuation due to fading.

Path loss exponents is dependent on the medium through which the signal propagates and generally the value is between 2 and 4 where value of 2 is obtain when propagation is across free space while 4 occurs in a lossy medium.

The Friis equation is used to calculate the power of a receiving antenna, with the distance from the transmitter as a function.

$$P_{recv} = P_T G_T G_R [\frac{\lambda}{4\pi R}]^2 \quad (4)$$

where

- P_T : transmitter power output
- G_T and G_R : gains associated with transmitting antenna and receiving antenna
- λ : wavelength of the microwave radiation
- R: separation of length in between the transmitter and receiver

The quantity of traffic existing across the communication link at a particular period of time also influences the utilization of energy in the network. To incorporate this aspect in the above model certain basic assumptions are made such as:

For successful reception at any node i, the schedule must satisfy that

(1) No data can be sent by a node 'i' while it is receiving data

(2) When node 'i' is receiving data from j, its neighbors cannot send any data except the neighbor j.

By incorporating these conditions, it is assumed that there is a conflict free transmission on the link.

$$P_i^{TD} = e_i^{TX} \alpha \sum_{i \in O_L} q_i + e_i^{RX} \overline{\alpha} \sum_{i \in I_L} q_i + e_s R_i \quad (5)$$

- P_i^{TD} : power dissipated due to traffic density at node i
- e_i^{TX} : energy utilized per bit in transmitting
- e_i^{RX} : energy utilized per bit in receiving
- e_s :energy utilized per bit in sensing
- R_i : Rate of generating sensory data
- R_i >0, node is a source
- R_i < 0, node is a coordinator
- R_i =0, does not participate in transmission
- α : is a system parameter which is a binary value (0/1)
- q_i : average amount of flow in the link

Another way of looking at the WSN is system is defining the energy consumption in terms of power. In this scenario, two important parameters such as the maximum transmission power of a node and data rate of the link are considered to be affecting the network lifetime.

Assume, at a given instant of time, a node i is sending a packet to node j with a probability 'τij'.

Then, the total energy utilized per unit time in a node i is

$$P_i = \sum_{j \neq i_i} \tau_{ij} (P^{TX} + p_{ij}) + \sum_{j \neq i} \tau_{ji} P^{RX} + P_p + \sum_{i,j \in S} k \times d_{ij}^{\ \gamma} + P_{TD} \quad (6)$$

where

- P_p : Power utilized by the node for processing
- P_t : Power utilized by the transmitter
- P_r : Power utilized by the receiver.
- p_{ij} is the transmitter power on the link at time' t' and is defined as

$$\begin{aligned} P(p_{ij}(t) = p_{ij}) &= \tau_{ij} \\ P(p_{ij}(t) = 0) &= (1 - \tau_{ij}) P_{TD} \end{aligned} \quad (7)$$

RESULTS

- There is no clear perception of the overall energy utilization of any complete application. The major components which play significant roles (players/ activities) of the traditional network model are considered individually and separately. This integrated approach has a modular structure, but still envelopes cross-layer ideas. This total energy cost function model can be used to optimize overall energy utilization, and decide the contribution of each component and their corresponding significance.
- Further, the relationship between these components and their influences on each other can be explored with this model.
- This proposed integrated approach can be incorporated in power management, and also can be employed to channelize the design of energy efficient wireless sensor networks.
- Incorporating AI into the model will lead to self organizing and self healing of the WSNs.

DISCUSSION

In this paper, arbitrary topology is used for simplicity. For real time systems, there will be a definitive topology plays a vital role in deciding the energy consumption by various constituents and ultimately the lifetime of the network.

The model is valid for networks having a stable topology and low mobility topology.

CONCLUSION

Due to number of constraints of resources in WSN and its nodes, there is a necessity to include AI and machine learning and schemes such as the joint sensor selection that can be implemented in WSN nodes, true for any type of topology. The existing network can be improvised by taking examples of realistic ones and incorporating the contributions of the constituent elements at micro or macro level.

REFERENCES

[1] Y. Chen And Q. Zhao, "On The Lifetime Of Wireless Sensor Networks", Communication Letters, IEEE, Vol. 9, No. 11, pp. 976-978, 2005.

[2] M. Ye, C. Li, G. Chen, And J. Wu, " EECS: An Energy Efficient Clustering Scheme In Wireless Sensor Networks", Performance, Computing, and Communications Conference, 2005, IPCCC 2005, 24th IEEE International, pp. 535-540, 2005.

[3] J. Ammer and J. Rabaey, "The energy-per-useful-bit metric for evaluating and optimizing sensor network physical layers", Sensor and Ad Hoc Communications and Networks, 2006. SECON'06 3rd Annual IEEE Communications Society on, Vol. 2, pp. 695-700, IEEE, 2006.

[4] Y. Wang, M.C. Varun, and S. Goddard, "Cross-layer analysis of the end-to-end delay distribution in wireless sensor networks", IEEE/ACM Transactions on Networking (TON), Vol. 20, No. 1, pp. 305-318, 2012.

[5] J. C. Park and S. K. Kasera, "Expected data rate: an accurate high-throughput path metric for multi-hop wireless routing", in SECON, pp. 218-228, 2005.

[6] J. J. Chang and L. Tassiulas, "Maximum lifetime routing in wireless sensor networks", IEEE/ACM Transactions on Networking (TON), Vol. 12, No. 4, pp. 609-619, 2004.

[7] P. Stanley-Marbell, T. Basten, J. Rousselot, R. S. Oliver, H. Karl, M. Geilen, R. Hoes, G. Fohler, and J.-D. Decotignie, "System models in wireless sensor networks", Rapport Technique, May, 2008.

[8] S. He, J. Chen, D. K. Yau, and Y. Sun, "Cross-layer optimization of correlated data gathering in wireless sensor networks", Mobile Computing, IEEE Transactions on, Vol. 11, No. 11, pp. 1678-1691, 2012.

[9] M. Elsersy, "Balancing energy consumption and average end-to-end delay for optimum routing protocol in wireless sensor networks", 2013.

[10] M. Cheng, X. Gong, and L. Cai, "Joint routing and link rate allocation under bandwidth and energy"

[11] F. Liu, C.-Y. Tsui, and Y.J.A. Zhang, "Joint routing and sleep scheduling for lifetime maximization of wireless sensor networks", IEEE Transactions on Wireless Communications, Vol. 9, No. 7, pp. 2258-2267, 2010.

[12] M. Buettner, G.V. Yee, E. Anderson, and R. Han, "X-MAC: a short preamble MAC protocol for duty-cycled wireless sensor networks", Proceedings of the 4th international conference on Embedded networked sensor systems, pp. 307-320, ACM, 2006.

[13] M. Kohvakka, "Medium access control and hardware prototype designs for low-energy wireless sensor networks", Tampereen teknillinen yliopisto. Julkaisu-Tampere University of Technology. Publication: 808, 2009.

[14] M. Kohvakka, T. D. Hamalainen, and M. Hannikainen, "Low-power Wireless Sensor Networks: Protocols, Services and Applications", Springer, 2012.

[15] L. Ding, P. Wu, H. Wang, Z. Pan, and X. You, "Lifetime maximization routing with network coding in wireless multihop networks", Science China Information Sciences, Vol. 56, No. 2, pp. 1-15, 2013.

[16] B. Jang, J. B. Lim, and M. L. Sichitiu, "An asynchroNous scheduled MAC protocol forwireless sensor networks", Computer Networks, Vol. 57, No. 1, pp. 85-98, 2013.

[17] M. N. Halgamuge, M. Ukerman, K. Ramamohanarao, and H. L. Vu, "An estimation of sensor energy consumption", Progress In Electromagnetics Research B, Vol. 12, pp. 259-295, 2009.