Energy Management for Wireless Sensor Network Nodes

Amit Sharma[1], Kshitij Shinghal[2], Neelam Srivastava[3], Raghuvir Singh[4]
[1]Deptt. of E&C Engg., K.I.M.T., Moradabad, U.P.,India.
[2]Department of E&C Engg., M.I.T, Moradabad, India.
[3]Department of E&C Engg., I.E.T, Lucknow, India.
[4]Academic Advisor, Shobhit University, Merrut, India.

Abstract:

Wireless sensor networks consist of small, autonomous devices with wireless networking capabilities. In order to further increase the applicability in real world applications, minimizing energy consumption is one of the most critical issues. Therefore, accurate energy model is required for the evaluation of wireless sensor networks. In this paper, the energy consumption for wireless sensor network (WSN) node is analyzed. To estimate the lifetime of sensor node, the energy characteristics of sensor node are measured. Research in this area has been growing in the past few years given the wide range of applications that can benefit from such a technology. In this paper, analysis of energy consumption of a WSN node is analyzed with a proposed node. Based on the proposed model, the estimated lifetime of a battery powered sensor node can be increased significantly.

Keywords: Wireless Sensor Networks, Energy Consumption.

1. INTRODUCTION

Lifetime of wireless sensor node is correlated with the battery current usage profile. By being able to estimate the energy consumption of the sensor nodes, applications and routing protocols are able to make informed decisions that increase the lifetime of the sensor network. However, it is in general not possible to measure the energy consumption on sensor node platforms. Minimizing energy consumption and size are important research topics in order to make wireless sensor networks (WSN) deployable. As most WSN nodes are battery powered, their lifetime is highly dependent on their energy consumption. Due to the low cost of an individual node, it is more cost effective to replace the entire node than to locate the node and replace or recharge its battery supply [1-2]. Node lifetime is a frequently discussed topic in platform design and analysis. In the last couple of years new platforms have demonstrated several new techniques for reducing power leakage during sleep time. Hardware components are characterized at a very detailed level to simulate power consumption of a node as close as possible. Another approach uses hybrid automata models for analyzing power consumption of a node at the operating system level [3]. In this paper describes an energy measurement system based on a node current consumption usage. To estimate the lifetime of activity monitoring system, the energy characteristics of sensor node is measured indirectly. One node is connected in series to a resistor. Using oscilloscope, voltage drop over the resistor is measured. Current is calculated using values given by the oscilloscope.

2. ENERGY MANAGEMENT

Energy management is important to the reliability of the network. The nature of the application may make it infeasible for interaction with the sensor once it has been deployed. Frequently the sensors are located in remote areas making it impossible to access them. In agricultural applications, it is unrealistic to think maintenance could be done on sensors. Sensors spread in a building damaged by an earthquake are also not reachable. An application that monitors the agricultural farms must not disturb the crop and soil. Economics is also a factor, when there are thousands of sensors; it is also unrealistic to have to be concerned with the power of a given sensor. Smart dust nodes are designed to be disposable, making it more cost effective to deploy additional new nodes rather than replace batteries in existing nodes. Many wireless sensor applications require the sensors to be operational for many years. It is thus essential that the sensors are reliable and work on their own for the duration of the application. If the sensor loses power, it is gone and so is the reliability of the network.

3. METHODS OF ENERGY MANAGEMENT

Communication is the primary consumer of energy in wireless networks. [2] It has been observed that a node requires almost as much energy to listen as it does to transmit data in short-range RF communications. Energy management techniques include those that reduce communication and increase computation, power down certain components of the node or the entire node, nodes that cover smaller areas, and renewable sources of energy. The desire to save energy has also affected routing algorithms, scheduling, data collection and aggregation and MAC (Medium Access Control) protocol research. The tradeoff between energy savings and latency are of major concern. Some time critical applications cannot tolerate delay in packet delivery.

4. DATA REDUCTION TECHNIQUES

It is desirable to reduce the amount of data that needs to be transmitted between nodes because the cost of transmission is high. Data aggregation methods are used to minimize the amount of redundancy in the data that needs to be transmitted. Although the processor consumes power during this process, it is much less than that consumed by the transmitting and receiving tasks. LEACH (Low-Energy Adaptive Clustering Hierarchy) is a cluster based protocol that uses hierarchy to reduce the data collected by the sensors before sending it on to a central base node. The energy load is evenly distributed among the sensors in the network. Simulations show energy dissipation can be reduced by much as a factor of 8 compared to conventional routing protocols. [12] The lifetime of the individual sensors is also increased because the energy is dissipated evenly among the sensors in the network.

5. ALGORITHMS TO CHOOSE THE CLUSTER THAT A NODE JOINS

Some algorithms are designed to conserve energy by having a node join the most appropriate cluster. Information is collected by the cluster leader and passed along in the network.

5.1. Nodes switch between active (on) and sleeping (off) mode [4]

Many different studies have been done that involve nodes switching between an active and sleep mode. The variables include how to determine the active/sleep schedule, the duration of the active/sleep period, and whether or not the nodes are aware of the schedules of the other nodes in the network. In order for the network to be reliable, events must not be missed. The nodes need to be able to sleep, but still respond to the events of interest. TinyOS supports this capability.

5.2. Nodes are independent

In research [4] the nodes switched between active and sleeping mode independently of each other. The sensors are distributed based on a Poisson process. Nodes are responsible for sensing a particular area and sending data to the sink node in multiple hops, using other nodes to relay the message. The sink node is always connected. The network is always disconnected because the number of nodes active at any given time is very low. Nodes spend more time sleeping than awake. Once a node senses an event, it stays active and sends the information to all of the nodes that are reachable in 1 hop. The node keeps transmitting the information until all of its immediate neighbors have received the information, since they can only receive the message if they are awake. Once all of the neighbors have gotten the message, the node can go back to its schedule of active and sleep time. All of the neighbor nodes repeat this process until all of their immediate neighbors get the message. The process continues until the message reaches the sink node.One obvious problem is the delay (latency) introduced by a message trying to reach a sleeping node. Latency is acceptable in some applications such as those that gather statistical information. Time critical applications such as those that send an alarm when an unexpected event occurs are much less tolerant of latency. Latency is affected by random placement of the nodes, random radio range, sensing distance and random sleeping and active periods of the nodes. Even applications that can tolerate latency would not tolerate a high degree of variability in the amount of latency. The latency will be larger as the node gets farther away from the sink node.The study showed that the latency was linearly proportional to the distance from the sink node. Some time critical applications can use this method by adjusting the dependent variables to make the latency in message delivery tolerable.

5.3. Physical Layer aware protocol

Wireless node exposes all of the underlying parameters of the physical hardware to the system designer. All layers of the system, including algorithms, operating systems, and network protocols can use this flexibility to adapt and conserve energy.

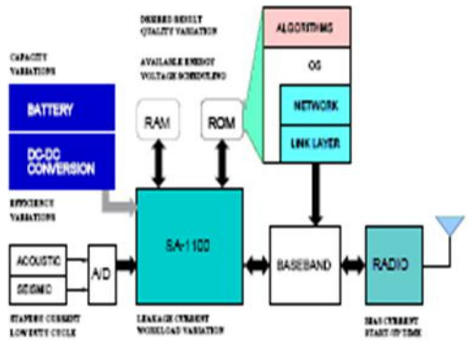

Figure 1. Architectural view of microsensor node

The system they measured consisted of separate components: a WSN node microprocessor, a sensor connected to and A/D converter, RAM and flash ROM for data and program storage, and a radio subsystem.

Table 1: Useful sleep states for the sensor nodes

State	**WSN node µp**	**Sensor, A/D**	**Radio**
Active (s_0)	Active	Sense	Tx/Rx
Ready (s_1)	Ideal	Sense	Rx
Monitor (s_2)	Sleep	Sense	Rx
Observe (s_3)	Sleep	Sense	Off
Deep Sleep (s_4)	Sleep	Off	Off

Table 2: Sleep state power, latency and thresholds

State	**P_k(mW)**	**τ_k(ms)**	**$\tau_{th,k}$(ms)**
Active	1040	-	-
Ready	400	5	8
Monitor	270	15	20
Look	200	20	25
Sleep	10	50	50

One observation is the "deeper" the sleep state, the greater the energy savings, and the longer the wakeup time. The research points out that care must be taken to make sure that more energy isn't consumed by putting the node to sleep and waking it up than leaving it awake constantly. Since current commercial radio transceivers have a high overhead to turn on and off, it is essential that wireless sensor networks allow the upper layers to adapt the hardware based on changes in the system in order to conserve energy at the node level. [12].

6. EVENT BASED COMMUNICATION

In this event based communication model, nodes subscribe only to event types they are interested in. Each node is scheduled to receive data, transmit data and power its radio down to a low-power standby mode. An event scheduler dynamically schedules time slots for each type of event. There is a root node that acts as the base station with greater computational, transmission and storage capability. Nodes save power by powering down their radio during those time slots that do not match the events they are interested in.
The Topology-Divided Dynamic Event Scheduling (TD-DES) protocol organizes the wireless network into a multi-hop network tree [2]. The result of the study indicated that TD-DES was efficient for conserving power, but has the disadvantage of introducing latency in the form of more multi-hop events.

7. REDUCE THE POWER CONSUMED BY THE SENSING TASK

The less area a sensor covers, the lower the amount of energy it consumes. The application determines the frequency of the sensing activity, but there is still an opportunity to reduce power consumption by the sensing task by decreasing the coverage area of a particular sensor. In order to cover the area completely, the number of sensors used by the application needs to be increased. This method can greatly increase the life expectancy of a particular sensor.

8. SHORTER HIGHER QUALITY LINKS Vs. LONGER LOSSY LINKS

Many network routing schemes try to send packets to the neighbor node that is closest to the sink node. This seems efficient because fewer hops are required to deliver the packet. The problem arises when the links to these nodes are lossy, meaning they have a high amount of data loss. Unreliability in wireless links can cause energy loss, because packets need to be retransmitted. Research [3] involves a forwarding scheme that relies on shorter more reliable links for a packet to reach its destination. The scheme blacklists neighbors that have been shown to have weak links. If the geographic forwarding scheme attempts to minimize the number of hops by maximizing the geographic distance covered at each hop (as in greedy forwarding), it is likely to incur significant energy expenditure due to retransmission on the unreliable long weak links. On the other hand, if the forwarding mechanism attempts to maximize per-hop reliability by forwarding only to close neighbors with good links, it may cover only a small geographic distance at each hop, which would also result in greater energy expenditure due to the for more transmission hops for reach packet to reach the destination [10]. The study shows that the optimal choice is nodes located somewhere in between the farthest and closest neighbor to the node transmitting the data.

9. SCAVENGING ENERGY

The amount of power consumed by the processing and communications tasks is also dependent on the hardware. Researchers are trying to reduce energy consumption in Wireless Sensor Networks by concentrating on the hardware. One method they are exploring is using custom RF integrated circuitry to *scavenge* energy from other resources such as solar and vibration sources. A study by [12] indicates that 100% of the necessary power can come from the sun, while vibration can contribute about 2.6% of the needed power. Radio uses the simplest processor, with hardware accelerators, and clocks with the lowest frequency, with a maximum operational voltage of 1 Volt. They have also found that increasing the data rate reduces the overall power consumption of the WSN Node.

10. HARDWARE DEVELOPMENTS

The development of sensor network hardware is showing the trend for more capability for the same amount of power consumption. "For all platform classes except special-purpose sensor nodes, Moore's Law promises an increase in performance for a given power budget" [5]. Special purpose sensors use advances derived from Moore's Law to reduce the power consumption and maintain the same level of performance. The following table, also taken from [5], shows that the WSN node, developed in 2001, has about eight times as much memory and communication bandwidth as its predecessor, the Rene node, developed in 1999. The cost and power consumption is the same for both.

11. WSN node Power Consumption

The following table shows the power consumption by the various components of the WSN Node[15]. Full operation of the sensor requires an average of ~ 15ma of current. AA batteries are about 1800 mA, which means they would last about 120 hours or 5 days. Lithium batteries may also be used, but they are more expensive and decay more rapidly than AA batteries.

Table 3: WSN Node System Specifications.

Currents	Value(units)
Microprocessor	
Current (full operation)	6mA
Current Sleep	8µA
Radio	
Current in Receive	8mA
Current transmit	12mA
Current sleep	2 µA
Flash Serial Memory	
Write	15mA
Read	4mA
Sleep	2 µA
Sensor Board	
Current (full operation)	5mA

The energy consumption *W* was measured in six representative operating modes, based on these measurement the model was formulated. The expression is given in Equation 1 with a description of the variables given in Table 1.

$$W = \frac{(N \bullet (E_{TX\_PIR} + E_{PIR\_LED} + E_{SLEEP}) + E_{TX\_TIME} + 3V \bullet I_{SLEEP} \bullet (3600-(N+1)sec)}{(3600 sec/h)} \quad (1)$$

Where *N* is a number of sensor per one hour.
Sensing modules powered two 1.5V (2000mAh) AA batteries. Total lifetime is given Equation 2.

$$Lifetime[h] = \frac{3V \times 2000mAh}{W} \quad (2)$$

The lifetime trend at different number of sensor firing is shown in Figure 2.

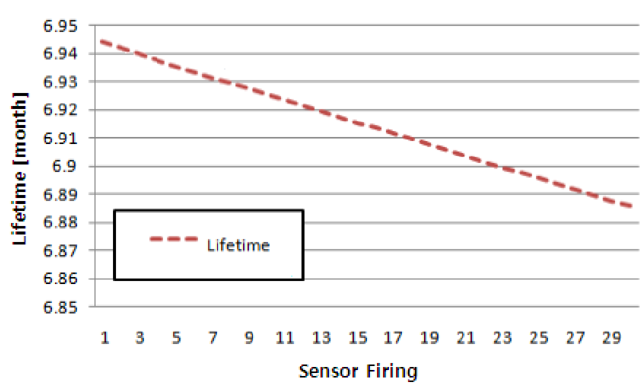

Figure 2. Lifetime vs. sensor firing

In the simulation experiments for 4 months, average number of sensor firing is 10 times per hour. Based on the proposed model, the estimated lifetime of a battery powered sensor node can be significantly increased.
In order to check battery voltage in sensing module, we measured interval voltage of MCU from ADC. Figure 3 shows the battery voltage drop.

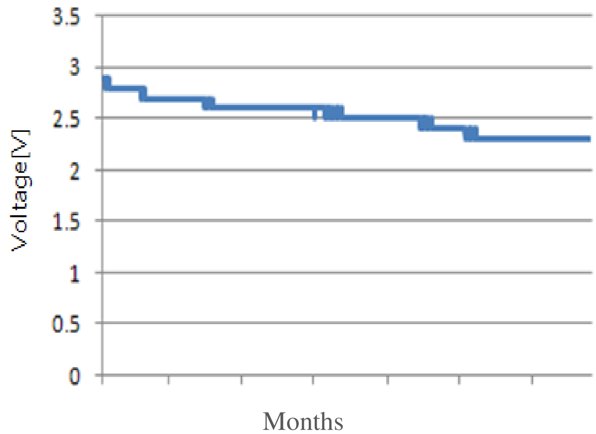

Figure 3. Battery voltage drop

12. CONCLUSION

Many factors can influence the energy consumption in wireless sensor networks. A lot of research is being done in this area. It is apparent that focusing on any one of these things and ignoring all others may result in consuming energy unnecessarily. In this paper, the energy consumption for wireless sensor networks is analyzed. To estimate the lifetime of sensor node, the energy characteristics of sensor node based on WSN node is measured. Based on the proposed model, the estimated lifetime of a battery powered sensor node can use about 6.5 months for 10 times sensor firing per hour. The simulation experiments showed that the sensor node works for approximately 7 months.

References

[1] Beutel, Jan. Geolocation in a PicoRadio Environment. Masters Thesis. 2000, 9.
[2] Cetintemel, Ugar, Flinders, Andrew, and Sun, Ye. Power-Efficient Data Dissemination in Wireless Sensor Networks. International Workshop on Data Engineering for Wireless and Mobile Access Proceedings of the 3rd ACM international workshop on Data engineering for wireless and mobile access. 2003, 1-8.
[3] Chen, Wei-Peng and Sha, Lui. An Energy –Aware Data-Centric Generic Utility Based Approach in Wireless Sensor Networks. Information Processing In Sensor Networks Proceedings of the third international symposium on Information processing in sensor networks. 2004, 215-224.
[4] Dousse, Olvier, Mannersalo, Petteri, and Thiran, Patrick. Latency of Wireless Sensor Networks with Uncoordinated Power Saving Mechanisms. International Symposium on Mobile Ad Hoc Networking & Computing Proceedings of the 5th ACM international symposium on Mobile ad hoc networking and computing. 2004, 109-1200.
[5] Hill, Jason, Horton, Mike, Kling, Ralph, and Krishnamurthy, Lakshman. The Platforms Enabling Wireless Sensor Networks. Communications of the ACM June 2004/ Vol47. No. 6. ,41-46.
[6] Polastre, Joseph, Hill, Jason, and Culler, David. Versatile Low Power Media Access for Wireless Sensor Networks. Conference On Embedded Networked Sensor Systems Proceedings of the 2nd international conference on Embedded networked sensor systems. 2004, 95-107.
[7] Rabaey, Jan M., Ammer, M. Josie, Silva, Julio L. da, Jr., Patel, Danny, Roundry, Shad. PicoRadio Supports AdHoc Ultra-Low Power Wireless Networking. Computer Magazine (July 2000), 42-44.
[8] Savarese, Chris. Robust Positioning Algorithms for Distributed Ad-Hoc Wireless Sensor Networks. Masters Thesis. 2002, entire thesis.
[9] Savarese, Chris, Rabaey, Jan M., Beutel, Jan. Locationing in Distributed Ad-hoc Wireless Sensor Networks. IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP). 2001, 2037-2040.
[10] Seada, Karim, Zuniga, Marco, Helmy, Ahmed, and Krishnamachari, Bhaskar. Energy-Efficient Forwarding Strategies for Geographic Routing in Lossy Wireless Sensor Networks. Conference On Embedded Networked Sensor Systems. Proceedings of the 2nd international conference on Embedded networked sensor systems. 2004, 108-121.

[12] Shih, Eugene, Cho, Seong-Hwan, Ickes, Nathan, Min, Rex, Sinha, Amit, Wang, Alice, and Chandraskasan, Anantha. Physical Layer Driven Protocol and Algorithm Design for Energy-Efficient Wireless Sensor Networks. International Conference on Mobile Computing and Networking. Proceedings of the 7th annual international conference on Mobile computing and networking. 2001, 272-287.
[13] Stemm, Mark, and Katz, Randy H, "Measuring and reducing energy consumption of network interfaces in hand-held devices," *IEICE Transactions on Communications*, vol. E80-B, no. 8. Aug 1997, 1125–1131.
[14] Wei Ye; Heidemann, J.; Estrin, D. An energy-efficient MAC protocol for wireless sensor networks**;** INFOCOM 2002. Twenty-First Annual Joint Conference of the IEEE Computer and Communications Societies. Proceedings. IEEE Volume 3, 23-27 June 2002, 1567 - 1576 vol.3.
[15] Wei Ye; Heidemann, J.; Estrin, D. Medium Access Control With Coordinate Adaptive Sleeping for Wireless Sensor Networks. IEEE/ACM TRANSACTIONS ON NETWORKING, VOL., 12, NO3, JUNE 2004,493-506.