Journal of Engineering and Applied Sciences 3 (11): 893-904, 2008
ISSN: 1816-949X

Predictive Modeling for Energy Conservation in Wireless Sensor Networks (WSNs)

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Abstract: Energy conservation in wireless sensor nodes has posed a big problem and limits the applications and deployment of wireless sensor networks. This study proposes, an alogrithm to minimize energy consumption in the nodes so as to extend the life time of the sensors. It does this by generating a prediction model from the readings received from the sensor nodes in the sensed field for sometime. The readings are then used to generate a model at the base station and sent back to the sensor nodes. The software for the generation of the prediction model is developed using Visual Basic Version 6.0. The software so developed allows the monitoring entity to set various sleeping modes for the sensor nodes. The nodes compare their recent readings with the predicted model received from the base station and transmit their readings only when they are below or above a certain specified threshold. The experiment was set up using Rene mote fitted with temperature sensor. Five of such Rene motes were placed in different locations with the 6th as the base station. The set up was run for 1 h in the first instance in the update mode with the frequency of 1, 5 and 10 sec. It was then repeated for another 1 h using the prediction model. The result showed the research achieved a considerable energy reduction in the sensor nodes. The energy conservation obtained varied from 23-97% and depend on the frequency of sensing.

Key words: Wireless, sensor, energy conservation, prediction model, applications, deployment

INTRODUCTION

Advances in Micro Electromechanical systems (MEMs) technology, digital electronics, embedded systems and wireless communications opened the way to a new class of networks called Wireless Sensor Networks (WSNs). Emerging Wireless Sensor Networks (WSNs) offer extremely flexible and low cost possibilities for monitoring and information collection for a wide range of environmental variables and applications not previously achieved with standard technologies (Simon and Farrugia, 2004). In WSNs, each node consists of one or more sensors, an embedded processor and a low powered radio and a battery operated power supply. WSNs have a wide range of potential applications including security and surveillance, control, actuation and maintenance of complex systems and fine grain monitoring of indoor and outdoor environmental conditions. WSNs usually involve a large number of spatially distributed energy constrained, self configuring and self aware nodes. They tend to be autonomous and require a high degree of co-operation and adaptation to perform the desired coordinated tasks and networking functions. However, energy conservation in wireless sensor nodes has posed a big problem and limits its applications and deployments.

Co-operative sensing raises several interesting research issues. A majority of these are rooted in the fact that sensors are typically limited by their energy reserves, communication bandwidth and computational power. Of these, the energy constraint is the most severe because if the sensor runs out of battery, there can be neither communication nor computation. Another constraining factor that is specific to wireless sensor networks is that the cost of managing the sensor nodes far exceeds the cost of the nodes themselves. The environment in which the sensors are deployed could make human maintenance difficult, for example, where they are scattered over a high-altitude region. A reasonable-sized sensor network will comprise of thousands of nodes. The sheer number of these nodes makes it difficult to manage. Finally, increasing hardware integration and economy of scale are currently driving the prices of sensors down. All these

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make use-and-throw a very attractive option where sensors that either have run out of battery or have failed are simply discarded and more sensors are thrown in to compensate for them (Goel and Imielinski, 2001).

Given these characteristics, the average lifetime of a sensor determines the cost of running a sensor network. Going by the current technological trend, while the computational power in sensors is expected to follow Moore’s law, the battery technology is only expected to improve by 2-3% per year (Rabaey, 2000). Thus, the only possible way one can increase the lifetime of a sensor is by making use of mechanisms that are highly energy-efficient. It is a known fact that every operation at a sensor node be it transmitting data, receiving data or performing a computation consumes, some energy. The essence of being energy efficient translates into the problem of optimizing the number of these operations that need to be performed. At the sensor node, the energy consumed in transmitting a packet has been found to be approximately twice the energy consumed in receiving a packet (Hill *et al*., 2000a). Also, the energy consumed in receiving a packet is an order of magnitude higher than the energy consumed per instruction execution (Heinzelman *et al*., 2000). Given this relative cost, one may achieve a reduction in total energy consumption by cutting down the number of high energy operations at the cost of an increase in the number of low energy operations.

In this study, we propose mechanisms for performing monitoring in a wireless sensor network in an energy efficient way. In traditional sensing paradigm, a central server maintains a database of readings from all the sensors. Sensors update the server when their readings change. Monitoring operations is therefore, supported by the server which maintains the current state of all the sensors involved in the operation. There are too many data transmitted in such a system making it very energy inefficient. Two key observations are necessary to significantly improve the energy efficiency of monitoring operation.

Firstly, sensors in close proximity are likely to have correlated readings and in a majority of these cases, one can predict the reading at a sensor given the knowledge of readings of sensors around it and their past history. A base station may exploit this observation and predict the set of readings that a sensor is going to see in the near future (Goel and Imielinski, 2001). These predictions are represented concisely as a prediction-model and sent to the sensor. The sensor now needs to transmit its sensed data to the cluster head only when the data differs from the reading given by the prediction model by more than a certain pre-specified threshold. Secondly, the reliability of readings at the base station can be maintained indifferent to the existence of environmental noise (Yao and Gehrke, 2002). Then, sensors can remain in idle mode until request to transmit its reading by the cluster head is made.

In general, the prediction paradigm prevents a sensor from unnecessarily transmitting all the readings that can be successfully predicted at the cluster head thereby saving energy.

Statement of problem: Sensor networks operate under conflicting requirements of maintaining the desired value of information throughput while simultaneously maximizing the lifetime of individual nodes (Misic *et al*., 2006). In doing so, the characteristics of the operating environment have to be taken into account. The physical resource constraints of wireless sensor networks are in the following areas:

Communications: The bandwidth of wireless links connecting sensor nodes is usually limited on the order of a few hundreds kilobits per second.

Power consumption: Sensor nodes have limited supply of energy and energy conservation is one of the main system design considerations. Small batteries that can provide about 300 m Ah of capacity powering sensor node for approximately 1 year in the idle state and for 1 week under full load are already in existence. Currently, some nodes already have three different sleep modes with several orders magnitude of different power usages (Hill *et al*., 2000a).

Uncertainty in readings: Signals detected at physical sensors have uncertainties due to limitations of the sensor and may contain environmental noise. Sensor malfunction or loss of power below some acceptable threshold might generate inaccurate data and unfortunate sensor placement might bias individual readings.

Computation: Sensor nodes have limited computing power and memory sizes that restrict the types of data processing algorithms that can be deployed and intermediate results that can be stored on the sensor nodes.

Purpose of study: The purpose of the study is to develop a mechanism for performing monitoring in a wireless sensor network in an energy-efficient way. The mechanism, in which the central server maintains a database of readings from all the sensors is very energy inefficient. In such a system, sensors update the server whenever their readings change. Monitoring operation is supported by the server, which maintains the current state of all the sensors involved in the operation. Thus, there are too many messages sent in such a system thereby quickly draining the energy source.

However, it is a known fact that sensors in close proximity are likely to have correlated readings and in a majority of the cases one can predict the reading at a sensor given the knowledge of readings of sensors around it and their past history. An entity, say, a base station, can exploit this observation and predict a set of readings that a sensor is going to see in the near future.

Scope of study: As stated earlier, it is possible for a base station to predict the set of readings that a sensor is going to see in the near future. These predictions are represented concisely as a prediction-model and sent to the sensors. The sensors now need to transmit its sensed reading to the base station only when it differs from the reading given by the prediction model by more than a certain threshold.

This mechanism prevents a sensor from unnecessarily transmitting all the readings that can be successfully predicted at the base station thereby saving energy. This saving is obtained at the cost of extra computations at the base station for generating prediction-models and the extra cost of transmitting them. Given this tradeoff, the effectiveness of this research is dependent on the accuracy with which prediction models are generated and the percentage of readings that can be successfully predicted by them, without too much computational overhead.

This research project is therefore focused on developing an algorithm that saves power at the sensor nodes i.e. making the nodes energy-efficient. The algorithm so developed ensures that the sensor nodes can be designed without having different sleep modes as the sleep time may not be suitable for all purpose applications. It enables the user to determine the duration of the sleep time. In high frequency events, the duration of sleep time is very important and determines to a greater extent how reliable the results will be.

Prediction-based monitoring: The simplest approach to monitoring in sensor networks would be to have all the nodes send their readings to the base station whenever it changes. This is referred to as the up-date mode. The base station collects these updates and sends them to a sink node as shown in Fig. 1. Thus, at any point in time, a base station maintains the database of current readings of all the sensors under its control.

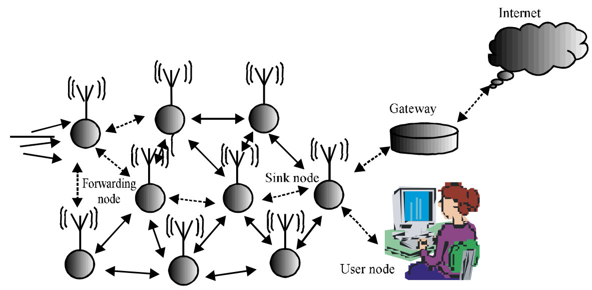

Fig. 1: Sensor network scenario

However, it is an axiom that a group of sensors is more effective in performing a sensing task than one powerful sensor (Muruganathan *et al*., 2005). In such a sensor network, a group of specially proximate sensors are very likely to have correlated readings. The correlation may be:

Spatial: The reading of a sensor being a function of the readings at nearby sensors.

Temporal: The reading at a sensor being a function of its reading in the past.

Absolute: The reading that a sensor is going to sense in the near future.

Spatio-temporal: That reading in sensor x in time slot t is the same as the reading of sensor y in the previous time slot.

The basic procedure for the prediction in this research is as follows: the base station monitors the reading of sensors for some time and generates a prediction model i.e., a concise representation of the readings that a sensor is expected to sense in the near future. It sends this to the appropriate sensors. On receiving a prediction model, sensors change their behaviour and instead of sending an update whenever their reading changes, they now send an update only when their readings differ from the one predicted by the prediction model.

Battery models in wireless sensor network: The battery is the sole source of energy of the sensor node. Although, the battery can be viewed as energy storage device, the main goal of this research work is to increase the lifetime of the battery to achieve the desired network reliability. Park *et al*. (2001) in their study proposed three different types of battery models to study how different aspects of real battery behaviour can affect the energy efficiency of different applications. The unit that is used to indicate the maximum capacity of the battery is the Ah (Ampere hour).

The unit is a common method used by the battery manufactures to specify the theoretical total capacity of the battery. Knowing the current discharge of the battery and the total capacity in Ah, the theoretical lifetime of the battery can be computed using:

$$T = \frac{C}{I} \quad (1)$$

where:

T = Battery lifetime
C = Rated maximum battery capacity in Ah
I = Discharge current

Linear model: In the linear model, the battery is treated as linear storage of current. The maximum capacity of the battery is achieved regardless of what the discharge rate is. The simple battery model allows user to see the efficiency of the user's application by providing how much capacity is consumed by the user. The remaining capacity after operation duration of time t_d can be expressed as followings:

$$C = C' - \int_{t=t_0}^{t_0+t_d} I(t)dt \ (Ah) \quad (2)$$

where:

C' = Previous capacity
I(t) = Instantaneous current consumed by the circuit at time t

Linear model assumes that I(t) will stay the same for the duration t_d if the operation mode of the circuit does not change (like Radio switching from receiving to transmit etc.) for the duration t_d. With these assumptions Eq. 2 simply becomes

$$C = C' - \int_{t=t_0}^{t_0+t_d} I(t)dt = C' - I.t \Big|_{t_0}^{t_0+t_d} = C' - I.t_d \quad (3)$$

The total remaining capacity is computed whenever the discharge rate of the circuit changes.

Discharge Rate Dependent Model (DRDM): While, Linear Model assumes that the maximum capacity of the battery is unaffected by the discharge rate, DRDM considers the effect of battery discharge rate on the maximum battery capacity. Park *et al*. (2001) showed that battery capacity is reduced as the discharge rate increases. In order to consider the effect of discharge rate dependency, they introduced a factor K, which is the battery capacity efficiency factor that is determined by the discharge rate. By definition

$$K = C_{eff}/C_{max}$$

where:

C_{eff} = Effective battery capacity (Ah)
C_{max} = Maximum capacity (Ah)

In DRDM, Eq. 3 is therefore transformed to the following:

$$C = K.C' - I.t_d \quad (4)$$

The efficiency factor K varies with the current I and is close to one when discharge rate is low, but approaches 0 when the discharge rate becomes high.

Relaxation model: Real-Life batteries exhibit a general phenomenon called relaxation as explained by Fuller *et al*. (1994), Linden (1995) and Chiasserini and Rao (1999). When the battery is discharged at high rate, the diffusion rate of the active ingredients through the electrolyte and electrode falls behind. If the high discharge rate is sustained, the battery reaches its end of life even though there are active materials still available. However, if the discharge current from the battery is cut off or reduced during the discharge, the diffusion and transport rate of active ingredients catches up with the depletion of the materials. This phenomenon is called relaxation effect and it gives the battery chance to recover the capacity lost at high discharge rate. This characteristic of the sensor battery is exploited in this research work by the introduction of sleep modes to enable the battery to recover the lost capacity thereby extending the lifetime of the whole network.

Prediction analogy: It has been stated in earlier section that sensors in close proximity are likely to have correlated readings and in a majority of the cases, one can predict the reading at a sensor given the knowledge of readings of sensors around it and their past history. An entity say base station or cluster head can exploit this

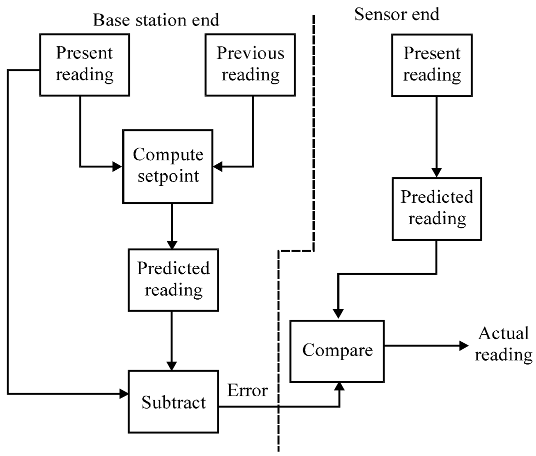

Fig. 2: Prediction-based model block diagram

observation and predict the set of readings that a sensor is going to see in the near future. These predictions are represented concisely as a prediction model and sent to the sensor. The sensor now needs to transmit its sensed readings to the monitoring entity only when it differs from the reading given by the prediction model by more than a certain pre-specified threshold. This model can be represented by a simple block diagram shown in Fig. 2.

MATERIALS AND METHODS

The experimental set up consists of 5 temperature sensors placed in areas where the temperatures are expected to vary in short space of time. Each temperature sensor is fitted with a Rene mote (http://tinyos.millennium.berkeley.edu/). A Rene mote is a tiny computational device with communication capability. It has an 8-bit microprocessor ATMEL AVR 90LS8535 and running at 4 MHz and a small flash memory of 8 KB program memory and 512 bytes data memory. The motes run a tiny micro-threaded operating system called TinyOS (Hill *et al*., 2000b).

A set of tools allows the motes to be extensively and easily programmed using a combination of C language and a component description language.

One of the main design criteria for motes was low power consumption. It draws 19.5 mA of current in active mode and can run for around 30 h on 2 AA batteries (Active mode means that the processor, sensors and radio are ON and transmitting). In inactive mode, the mote draws only 10 mA of current and can run for 1 year (Hill *et al*., 2000b). (Inactive mode means that the processor and radio are ON but sensor is listening but not transmitting).

A mote consumes 1 µJ on the average for transmitting one bit and 0.5 µJ to receive 1bit. Furthermore, it consumes 0.8 µJ of energy for executing 208 machine cycles (i.e., roughly 100) instructions (Hill *et al*., 2000b). A mote has a radio (RFM TR1000) on-board that works at 916 MHz. The radio can support a maximum bit rate of 19.2 kbps (on/off keying).

The temperature changes were however, induced as a way of crosscheck. Another mote acts as the base station. All sensors report to the base station once every 5 sec following the paradigm developed in the following study. The base station analyzes the readings of the sensors and generates predictions about future readings of the sensors. The sensors store predictions received and transmit their readings only when they do not match with the predicted values.

Program development: The program is developed using Visual Basic™ version 6.0 with temperature as the environment variable under investigation. The program allows readings from each sensor node every five seconds and holds them in the database, each time comparing the reading with the previous one. The average of this reading is recorded as the set point after 2 min. The base station then broadcasts this set-point to the nodes in the cluster and sets a threshold of value below and above this set-point which the node must read before sending its reading to the base station. The nodes are then put to sleep by the base station for a length of time specified by the base station and determined by the rate of change of the readings from the node. The program queries the nodes at interval that is set by the monitoring entity. If the reading in any sensor node is the same with the set-point or within a prescribed threshold, then the base station broadcasts another sleep time for the nodes referred to as the short sleep time. If not, the base station prompts the nodes to send their readings for the next two minutes. The procedure is repeated after an interval that is again set by the monitoring entity. If the readings are still within the set point or threshold, then a longer sleep time is broadcast to the nodes referred to as long sleep time. Else, the nodes are queried more often to determine the trend whether upwards or downwards. This is referred to as exceptional time in the program. If the readings get to an exceptionally high or low value called the critical point, then a conclusion can be drawn. At the end of the validity time, the system memory is cleared and the process starts all over. Fig. 3 shows the flowchart describing the program development.

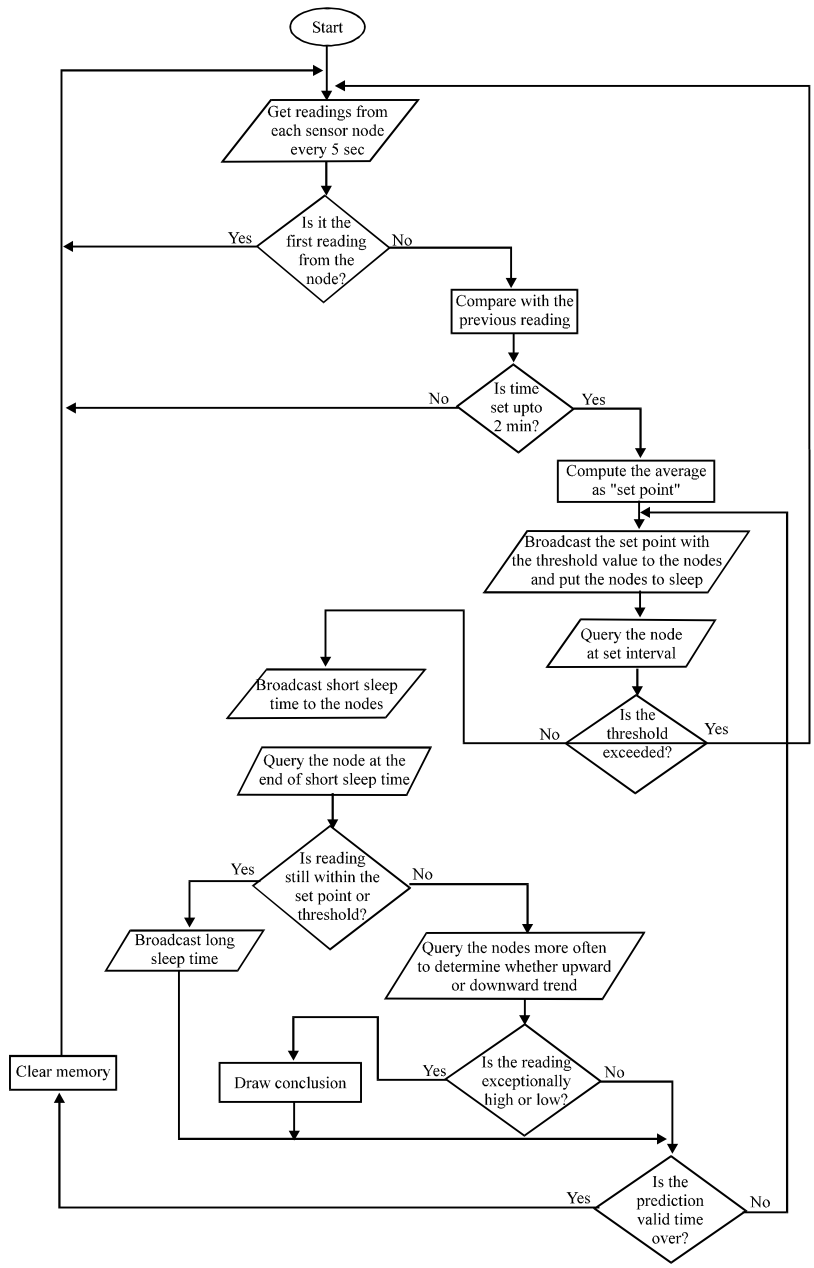

Fig. 3: Program development flowchart

RESULTS AND DISCUSSION

The program was tested with the set point put at 24°C. The short sleep time was set at 1 min and long sleep time at 5 min. The exceptional time was put at thirty seconds while the critical point was put at 31°C. During the test run, it was discovered that the nodes were in sleep mode for more than half the time. Altering the variables i.e. sleep times can further increase the duration of the time in which the nodes are in sleep mode thereby, extending the lifetime of the nodes. It is to be noted that the constraints on the quality of the result required by the monitoring entity govern the amount of energy savings that may be achieved.

The experiment was run for 1 h in 3 phases. These phases are referred to as case 1, 2 and 3.

Case 1: Case 1 is referred to as the update mode. In this mode, the sensors transmit their readings periodically once every 5 sec. The base station does not transmit any

Table 1: Basic operations in the mote

Operations	Type	Energy cost (µJ)	Energy cost per bit (µJ)
Transmit (T_u)	Update	88	1
Receive (R_u)	Update	44	0.5

Hill *et al*. (2006b)

predictions. The rated energy consumed in the sensor for each of the basic operations is listed in Table 1. Table 1 also, assigns a symbol for each basic operation and is used in this research.

In the update mode, the energy consumption at each sensor mote can be computed as follows; since, the experiment runs for 1 h (60 min), each sensor sent 12×60 = 720 updates (at the rate of 12 times/min) during the experiment. Therefore, the energy consumed at each sensor during the entire run of the experiment is given by

$$E_{sensor} = 720 \text{ updates} \times \text{Transmit energy cost } (T_u) = 720\times88 = 63.36 \text{ mJ}$$

Total Energy consumed in the sensors is given by:

$$TE_{sensors} = 720\times88\times5 = 316.8 \text{ mJ}$$

The base station sensor in the update mode receives 720 updates from each sensor during the entire run of the experiment. Therefore, the energy consumed at the base station sensor is given by:

$$E_{base\ station} = (\text{No. of updates received from each node}) \times (\text{Receive energy cost}) = 720\times44\times5 = 158.4 \text{ mJ}$$

Therefore, the total energy (TE_{update}) consumed in the system in the update mode is given by:

$$TE_{update(5)} = (\text{Energy consumed at the base station}) + (\text{Energy consumed by the node}) = E_{base\ station} + E_{Sensor} = 158.4 \text{ mJ} + (63.36\times5) \text{ mJ} = 475.2 \text{ mJ}$$

The experiment was repeated at a slower rate of once every ten seconds. Since, the experiment runs for 1h (60 min), each sensor sent 6×60 = 360 updates. Just like the first experiment, energy consumed in each sensor ($E_{sensors}$) is given by:

$$E_{sensors} = 360 \text{ updates} \times \text{Transmit energy cost } (T_u) = 360\times88 = 31.68 \text{ mJ}$$

Total Energy consumed in the motes is given by:

$$TE_{sensors} = 360\times88\times5 = 158.4 \text{ mJ}$$

The base station sensor in this case receives 360 updates from each sensor for the duration under consideration. Therefore, the energy consumed at the base station is given by:

$$E_{base\ station} = (\text{No of updates received from each node}) \times (\text{Receive energy cost}) = 360\times44\times5 = 79.2 \text{ mJ}$$

The total energy (TE_{update}) consumed in the system when the motes transmit every 10 sec in the update mode is given by:

$$Te_{update(10)} = TE_{sensors} + E_{base\ station} = (360\times88\times5) + (360\times44\times5) = 237.6 \text{ mJ}$$

The experiment was repeated for the third time with the rate of once every second. This translates to 3600 updates in 1 h.

$$E_{sensors} = 3600 \text{ updates} \times \text{Transmit energy cost } (T_u)$$
$$E_{sensors} = 3600\times88 = 316.8 \text{ mJ}$$

Total energy consumed in the motes:

$$TE_{sensors} = 3600\times88\times5 = 1584 \text{ mJ}$$

The base station mote in this case receives 3600 updates therefore; the energy consumed at the base station mote is given by:

$$TE_{base\ station} = 3600\times44\times5 = 792 \text{ mJ}$$

The total energy (TE_{update}) consumed in the system in this case is given by:

$$TE_{update(1)} = TE_{sensors} + E_{base\ station} = 3600\times44\times5 + 3600\times88\times5 = 237.6 \text{ mJ}$$

Figure 4 shows a graph of energy consumption in the update mode with varying frequency. From the result, the update mode consumes more energy when the frequency of sensing is very high, that is, the case of sensing and transmitting every second. Progressively, the energy consumption decreases with decrease in the rate of sensing. However, continual reduction in the sensing rate in the bid to conserve energy will eventually lead to the loss of track for high frequency events.

Figure 5 is a graph showing the rate of decrease in energy consumption with decreasing frequency of monitoring. From the results of the update mode, it can be seen that there is a correlation between the various rates

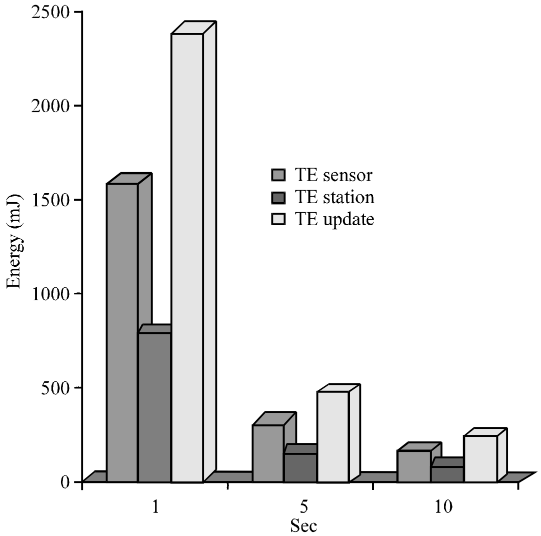

Fig. 4: Energy consumption in the update mode with varying frequency

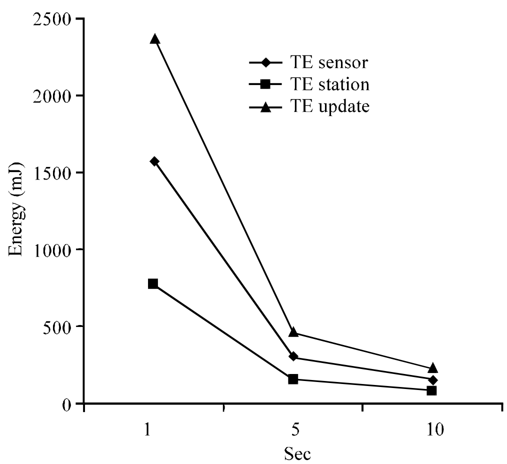

Fig. 5: Rate of decrease of energy consumption with decrease in frequency of monitoring

of monitoring. For instance, the total energy consumed in each sensor in the update mode doubled when the frequency of monitoring is changed from ten seconds to 5 sec and rose by 10 times when the frequency is changed to 1 sec. This clearly shows that further reduction in the frequency of monitoring will conserve more energy in the system. The same correlation holds for the total energy consumption in the base station vis-à-vis the energy consumption in the network.

Case 2: Case 2 is referred to as the extreme condition where the base station receives updates for 2 min and generates a prediction model. This prediction model is transmitted once to the sensors in 1 h. This gives the minimum energy value that can ever be consumed in the

Table 2 Summary of results of experiments in case 3

Sensors address	No. of predictions received	No. of transmissions saved
1	20	480
2	18	504
3	38	264
4	28	390
5	10	600

system and is computed as below. Assume the situation where, the sensors receive predictions once and the temperature did not exceed the set threshold in 1 h. The total energy consumed in the system is computed thus.

TE_{sensor} = (No. of updates – No. of updates saved) T_u + (No. of predictions) R_u

$TE_{sensor1}$ = $(720 - 696)T_u + (1)R_u = 24\times88 + 1\times44 = 2.156$ mJ

But the same energy is consumed in all the sensors in this instance:
Therefore:

$$TE_{sensor1} = TE_{sensor2} = TE_{sensor3} = TE_{sensor4} = TE_{sensor5}$$

The total energy consumed is then the sum of the energy consumed in the motes plus the energy consumed in the base station in receiving the updates for 2 min.

$$TE_{sensor1\text{-}5} = 2.156\times5 = 10.78 \text{ mJ}$$

Energy consumed at the base station.

$TE_{base\ station}$ = (No. of updates received)R_u + (No. of predictions generated) T_u
= $24\times44 + 5\times88 = 1.496$ mJ

Therefore, the total energy consumed in the system is

$$1.496 \text{ mJ} + 10.78 \text{ mJ} = 12.28 \text{ mJ}$$

Comparing this result with that of case 1, it can be seen that it is possible to have about 97% save in energy consumption for a given period of time in the life of a mote while in operation.

Case 3: Case 3 is referred to as the prediction mode case. In this case, all the sensors and the base station operate in the prediction mode and follow the technique presented in this research. The result of the experiment in the prediction mode is shown in Table 2.

Based on the result, the energy consumed in each of the sensors and the base station is computed. The result is then compared with that of the update mode. The sensors are labeled from number 1-5.

The temperatures of the nodes were changed arbitrarily within the 1 h of test run to achieve 2 things. First to ensure the efficacy of the program developed and secondly, to ascertain that the base station generates the prediction models and that the prediction model gets to the sensors they are intended to address.

The total energy consumed at the base station is the sum of the energy consumed in receiving updates, generating predictions and sending predictions.

Energy consumed in one mote in this circumstance is given by:

No. of transmission N_{TX} = (No. of updates that would have been transmitted by the sensors) – (No of update saved by using the prediction model).

$Te_{sensor1}$ = (No. of updates – No of updates saved)T_u + (No. of predictions received)R_u

Therefore,

$TE_{sensor1}$ = (720 – 480)88 + (20)44 = 22.00 mJ
$TE_{sensor2}$ = (720 – 504)88 + (18)44 = 19. 80 mJ
$TE_{sensor3}$ = (720 – 264)88 + (38)44 = 41. 80 mJ
$TE_{sensor4}$ = (720 – 390)88 + (31)44 = 30.40 mJ
$TE_{sensor5}$ = (720 – 600)88 + (12)44 = 11.09 mJ

Therefore, the total energy consumed in the sensors is given by:

TE_{sensor} = $TE_{sensor1}$ + $TE_{sensor2}$ + $TE_{sensor3}$ + $TE_{sensor4}$ + $TE_{sensor5}$
= 22.00 + 19. 80 + 41.80 + 30.40 + 11.09= 125.09 mJ

Total energy consumed in the base station is computed as shown.

$TE_{base\ station}$ = (No. of updates received from node 1)R_u + (No. predictions sent to node1)T_u + (No. of updates received from sensor 2)R_u + (No. of predictions sent to sensor 2)T_u + (No. of predictions sent to sensor 3)R_u + (No. of predictions sent to sensor 3)T_u + (No. of predictions sent to sensor 4)R_u + (No. of predictions sent to sensor 4)T_u + (No. of predictions sent to sensor 5)R_u + (No. of predictions sent to sensor 5)T_u

$TE_{base\ station}$ = (720 – 480)44 + (20)88 + (720 – 504)44 + (18)88 + (720 – 264)44 + (38)88 + (720 – 390)44 + (31)88 + (720 – 600)44 + (12)88
= 10.560 + 1.760 + 9.504 + 1.584 + 20.064 + 3.344 + 14.520 + 2.728 + 5.280 + 1.056
= 70.400 mJ

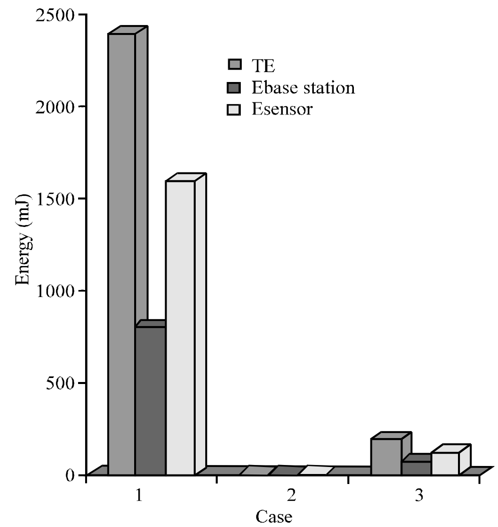

Fig. 6: Comparison between the 3 cases with 1 sec frequency of monitoring

Therefore, the total energy consumed in the prediction mode is:

$TE_{pre\text{-}mode}$ = Total energy consumed at the base station + total energy consumed at the nodes = 70.400 + 125.090 = 195.49 mJ

From the computations the total energy consumption in the prediction mode case is 8.2% of the total energy consumption in the update mode when the frequency of sensing is 1second. This gives a conservation of 91.8%. When the frequency of sensing is 5 sec, the energy consumption is 41.4% of the energy consumption in the update mode. This translates to 58.6% energy conservation. When the frequency of sensing is set to 10 sec, the energy consumption in the prediction case is 82.3% compared to the energy consumed in the update mode. This also translates to 17.7% conservation of energy.

Further analysis, shows that even though the energy consumed during the 10 sec is low, high frequency events can not be effectively monitored. Also, continued decreasing of the frequency of sensing will eventually lead to a point where the prediction case will consume more energy. Figure 6-8 are a set of graphs showing comparison between the 3 cases.

Summary of related works: Researchers in wireless sensor networks have looked at various ways of saving energy in sensors. In particular, Kulik *et al*. (1999), Heinzelman *et al*. (2000) and Heidemann *et al*. (2001) have

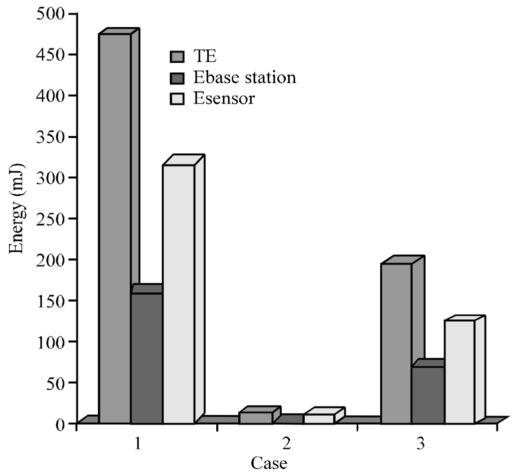

Fig. 7: Comparison between the 3 cases with 5 sec frequency of monitoring

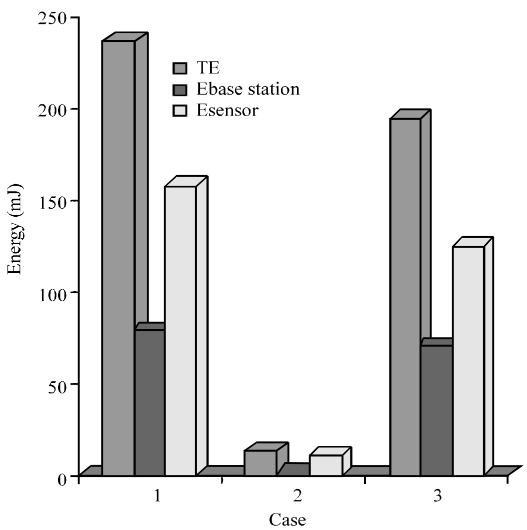

Fig. 8: Comparison between the 3 cases with 10 sec frequency of monitoring

proposed exploiting redundancy in sensed readings of sensors that are in close proximity. However, the approaches proposed Kulik *et al*. (1999) rely on sensors to figure out among themselves the redundant part in their sensed information and suppress it from transmission. There are three clear limitations to this approach.

Firstly, it will take N transmissions for a group of N sensors to figure out all the redundant information, which is costly and may outweigh the advantage of removing redundancy. Secondly, in cases when the sensed readings are complex (like image from a camera), it is not clear how one may determine the redundant part given the limited computational power at the sensors. Thirdly, this approach only minimizes the redundancy in information being sent and may study well in sensor networks like network of temperature sensors where the sensed reading is not expected to vary much in a small spatial region.

The research reported here specifies mechanisms for identifying correlation in readings across time frame and try to eliminate the need for transmitting these if they can be derived from older readings. This is expected to translate into significant savings in energy.

In the research reported by Heinzelman *et al*. (2000), the researchers deal with the problem of how to self organize sensors that are thrown together so that a meaningful sensing task can be accomplished. The study prescribes compressing information at the nodes acting as cluster-heads before sending to a central station. However, it did not specify any mechanisms for performing this compression operation. Also, this approach does not prevent sensors from sending redundant information.

Intanagonwiwat *et al*. (2000) laid emphasis on being able to route data sensed at sensors to where the interest is. The study does not deal with cutting down the information being relayed.

Chang and Tassiulas (2000) suggested route selection in an ad hoc network based on available energy in order to increase network life time.

Heinzelman *et al*. (1999) presented the SPIN family of network protocols for communication of large messages in sensor networks. They propose to first distribute metadata instead of flooding the network with actual data. The distribution of metadata eliminates duplicate transmission of the same data record.

The PAMAS MAC-level protocol turns radios off when they are not transmitting or receiving packets (Singh *et al*., 1998). TDMA protocols have been proposed to reduce energy consumption in sensor networks as shown by Pottie and Kaiser. By reducing the duty cycle, these protocols can trade idle-time energy consumption for latency. PicoNet proposes an integrated design of radios, small battery-powered nodes and MAC and application protocols that minimize power consumption (Bennett *et al*., 1997).

Other studies that have been carried out on energy conservation in wireless sensor networks include LEACH (Low Energy Adaptive Clustering Hierarchy) http://nms.lcs.mit.edu/projects/leach; LEACH-C; PEGASIS (Power Efficient Gathering in Sensor Information System) by Lindsey *et al*. (2000) and BCDCP (Base Station Controlled Dynamic Clustering Protocol) by Muruganathan *et al*. (2005).

RECOMMENDATIONS

In addition, what may be considered as future work or extensions to this research should deal with the following key issues but are not limited to; Performing simulations to analyze the performance of this mechanism (prediction model) over large sensor networks. Performing simulations to analyze the performance of the proposed mechanism over the monitoring of other variables like motion sensors and Determine the actual hours this mechanism can add to the lifetime of the sensor nodes.

CONCLUSION

This research effort is aimed at developing a power saving mechanism for performing monitoring operations in a wireless sensor network with temperature as the variable to be monitored. Five nodes were used for the demonstration and a computer as the cluster head of the sensor field. From the results obtained, it has been shown that it is possible to achieve up to 97% in energy savings in a wireless sensor network.

The research also, showed that there is a correlation between the frequency of sensing and energy consumption in the network. For instance, sensing every second consumes twice the energy used in sensing every 5 sec and 10 times the energy used when sensing is done every 10 sec.

It can also be concluded that from the research done here that sensing at a slower rate in the bid to save energy will lead to a loss error in sensing high frequency events.

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