

Efficient Energy Management in a Wireless Sensor Network using Duty Cycle and Pre-Emptive Time Scheduling Techniques

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Abstract

In this paper, the design and implementation of the duty-cycle, that is based on pre-emptive time scheduling is proposed, this work analyze the time it will take based on the period the variable is available to be read and also the energy required with respect to components in use. The implementation of the duty-cycle WSN platform was described including the hardware, firmware, different energy saving mode were developed and the result was obtained using Matlab. An analysis of the battery Ampere hour consumption was carried out with a view to seeking ways of enhancing Battery life. When fully charged the Nokia BL-5CB Battery has an ampere hour value of 1027 mAH, when subjected to sleep and active mode for 24 hours. The ampere hour value of the battery fell to 998 mAH for source node and 900 for mAH for intermediate nodes.

KEYWORDS: Duty Cycle, Ampere Hour, WSN

1.0 Introduction

Wireless sensor network (WSN) consists of a large number of tiny sensor nodes deployed over a geographical area also referred to as sensing field; each node is a low-power device that integrates computing, wireless communication and sensing abilities [1][2][3]. Nodes organize themselves in clusters and networks and cooperate to perform an assigned monitoring (and/or control) task without any human intervention at scales (both spatial and temporal) and resolutions that are difficult, if not impossible, to achieve with traditional techniques. Sensor nodes are thus able to sense physical environmental information (e.g., temperature, humidity, vibration, acceleration or whatever required), process locally the acquired data both at unit and cluster level, and send the outcome or aggregated features- to the cluster and/or one or more collection points, named sinks or base stations.[4,5]

In recent years, the number of wireless sensor network deployments for real life applications has rapidly increased. Still, the energy problem

remains one of the major barrier somehow preventing the complete exploitation of this technology. Sensor nodes are typically powered by batteries with a limited lifetime and, even when additional energy can be harvested from the external environment (e.g., through solar cells or piezo-electric mechanisms), it remains a limited resource to be consumed judiciously. Efficient energy management is thus a key requirement for a credible design of a wireless sensor network.

Most energy management strategies proposed in this paper assume that data acquisition consumes significantly less energy than their transmission. Unfortunately, this assumption does not hold in a number of practical applications where the power consumption of the sensing activity may be comparable or even greater than that of the radio. In this context, effective energy management strategies should include policies for an efficient use of energy-hungry sensors, which become one of the main components affecting the network lifetime. In this paper, we survey the main approaches for efficient energy

management in sensor networks with energy-hungry sensors.

1.1 Energy Saving Implementation Pre-Emptive Time Scheduling and Power Ratio Method

In implementing energy saving mode, we looked at various methods used with an intent to develop a hybrid from the two, this involves looking at the work from two perspectives, a Power ratio method is used for the implementation, take a look at the diagram in figure 1, the sensor is permanently kept on in order to monitor the parameter for the node whether there is data to be read or not the node is permanently kept ON, and due to the consistent ON state energy is lost even if there is no data to be read.

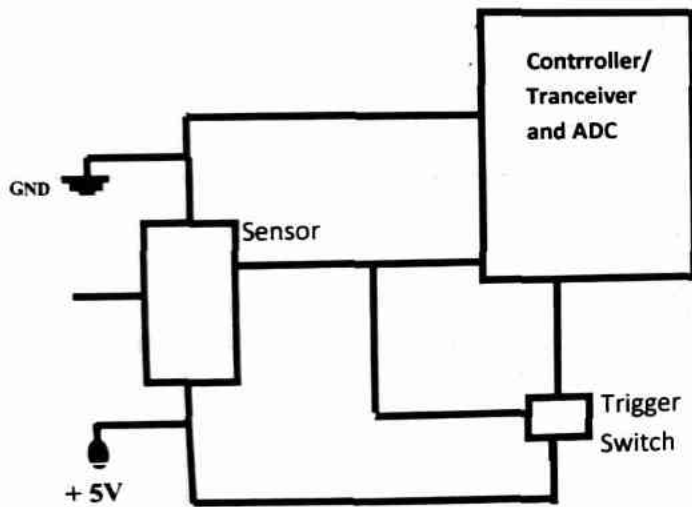


Figure 1 Architecture energy saving mode 1

The idea is to make sure that whenever there is data the sensor will trigger on the switch which will power on the entire circuit, note for figure 1 during sleep mode only the sensor is powered. The flowchart in Figure 4 describes the process of implementing Power saving Technique of Wireless Sensor System. The Sensor is kept on for as long as the circuit remains and whenever there is a signal the sensor triggers the switch on and the entire circuit is then connected to Power supply to bring up the active mode, and the moment there is no signal to be read the sensor triggers off the main circuit and a sleep mode is activated as represented in the flowchart in figure 4.

The Power Ratio method is used for the analysis. In figure 1, the circuit represented in blocks have assigned power rating.

P_S = Sensor Power Rating

P_T = Switch Trigger Power Rating

$P_{\mu c}$ = Microcontroller Power Rating

P = Standard Power rating

Active Mode

$$\text{Total Power Dissipated} = 2P_S + P_T + 3P_{\mu c} = 6P \quad (1)$$

Power rating becomes $2P_S : P, P_T : P, 3P_{\mu c} : P$

Energy consumed in Circuit, $E = \text{Power} \times \text{Time}$

When set in ACTIVE Mode, Energy Consumed is:

$$6P \times t = 6Pt = 6E \quad (2)$$

Note t = time

Energy consumed = $6E$

Sleep Mode

For sleep mode, only the Sensor and trigger switches are on

$$P_T + 2P_S = 3P \quad (3)$$

Energy consumed in Circuit, $E = \text{Power} \times \text{Time}$

When set in SLEEP Mode: Energy Consumed is

$$3P \times t = 3P_t = 3E \quad (4)$$

$$\text{Energy Saved} = \frac{3E}{6E} \times 100\% = 50\%$$

Energy is conserved by 50 %

1.2 A Second Alternative

This work refer to this as divide by two method because of the trade off of 50% when the sensor of anode is on to check if data is available to be read as this will make the sensor to sample and read data at every one millisecond, the sensor will be sampling to check if data is available to reduce the power consumed in the battery by half.

We implement the Energy consumption process using Power Ratio for Energy Saving mode 2 in figure 2

P_S = Sensor Power Rating

P_T = Switch Trigger Power Rating

$P_{\mu c}$ = Microcontroller Power Rating

P_{clk} = Timer Power Rating

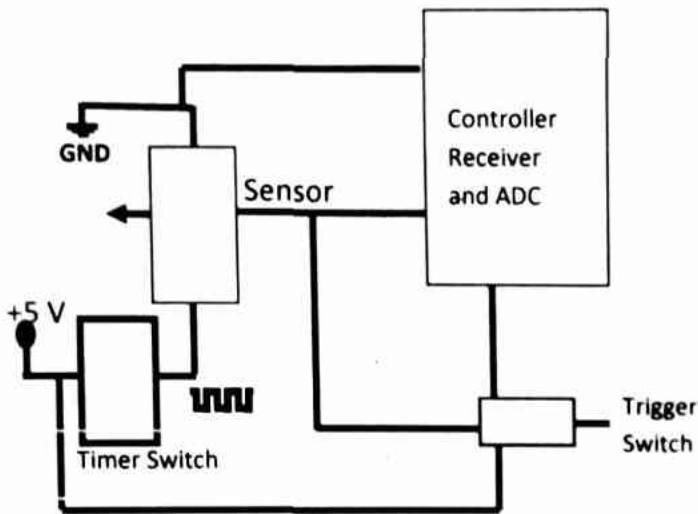


Figure 2 Architecture Energy Saving Mode 2

Active Mode

$$\text{Total Power Dissipated} = 2P_S + P_T + 3P_{\mu c} + 3P_{clk} \quad (5)$$

$$= \frac{7.5P}{2}$$

Energy consumed in Circuit, $E = \text{Power} \times \text{Time}$

When set in ACTIVE Mode Energy Consumed is:

$$7.5P \times t = 7.5Pt = 7.5E$$

Energy consumed 7.5E

Sleep Mode

For sleep mode, only the Sensor and trigger switches are on

$$P_T + 2P_S + \frac{3P_{clk}}{2} = 4.5P \quad (6)$$

Energy consumed in Circuit, $E = \text{Power} \times \text{Time}$

When set to Sleep Mode: Energy Consumed is

$$4.5P \times t = 4.5Pt = 4.5E \quad (7)$$

$$\text{Energy saved} = \frac{4.5E}{7.5E} \times 100\% = 60\%$$

Energy is conserved by 40 %

1.3 Hybrid Mode

This paper proposes and implements a hybrid mode it is Software based which was drawn from the two methods that have been analysed in figure 1 and 2, the work adopt the sleep and Wake method directly from the embedded software. The microcontroller is made to sample the sensor every 10 micro seconds, whenever there is a signal(Data) to be measured(read) the active mode routine in the software program is called we analyse this from the duty cycle in figure 3, this two way block explains how simple the system look like.

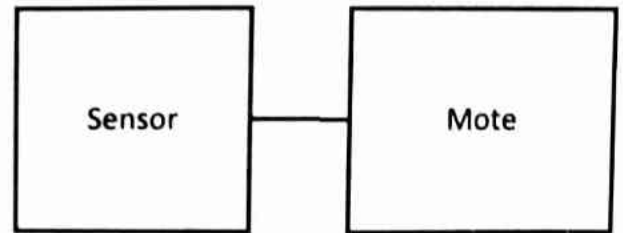


Figure: 3 Simple Hybrid Power Mode

We implement the Energy consumption using Power Ratio for Energy Saving mode 3 in figure 3

P_S = Sensor Power Rating

$P_{\mu c}$ = Microcontroller Power Rating

Active Mode

$$P_S + 3P_S = 4P_S \quad (8)$$

Energy consumed in Circuit, $E = \text{Power} \times \text{Time}$

When set in ACTIVE Mode, Energy Consumed is:

$$4P \times t = 4Pt = 4E \quad (9)$$

Energy consumed 4E

Sleep Mode

For sleep mode, only the Sensor, and trigger switch are on

$$2P_S + \frac{3P_{\mu c}}{2} = 2.5P \quad (10)$$

Energy consumed in Circuit, $E = \text{Power} \times \text{Time}$

When set in SLEEP Mode: Energy Consumed is

$$2.5P \times t = 2.5Pt = 2.5E \quad (11)$$

$$\text{Energy saved } \frac{2.5E}{7E} \times 100\% = 33\%$$

Energy is conserved by 60 %

As can be seen, this is the most preferred.

2.0 Battery Application & Technology

Since the entire working process of Wireless Sensor Node depends on availability of power, it therefore becomes imperative for us to carry out analysis and design of Power supply in Wireless Sensor System with respect to the Battery used [13,14].

In general terms, the *capacity* of a cell/battery is the amount of charge available expressed in *ampere-hours* (Ah). An ampere is the unit of measurement used for electrical current and is defined as a coulomb of charge passing through an electrical conductor in one second. The capacity of a cell or battery is related to the quantity of active materials in it, and the amount of electrolyte and the surface area of the plates. The capacity of a battery/cell is measured by discharging at a constant current until it reaches its terminal voltage (usually about 1.75 volts). This is usually done at a constant temperature, under standard conditions of 25°C (77°F). The capacity is calculated by multiplying the discharge current value by the time required to reach terminal voltage [10, 11].

The most common term used to describe a battery's ability to deliver current is its *rated capacity*. Manufacturers frequently specify the rated capacity of their batteries in ampere-hours at a specific discharge rate. For example, this

means that a lead-acid battery rated for 200 Ah (for a 10-hour rate) will deliver 20 amperes of current for 10 hours under standard temperature conditions (25°C or 77°F). Alternatively, a discharge rate may be specified by its charge rate or C-rate, which is expressed as a multiple of the rated capacity of the cell or battery. For example, a battery may have a rating of 200 Ah at a C/10 discharge rate. The discharge rate is determined by the equation below:[6,7]

$$\begin{aligned} C/10 \text{ rate (amperes)} &= 200\text{Ah}/10\text{h} \\ &= 20 \text{ Amps} \end{aligned}$$

Battery capacity varies with the discharge rate. The higher the discharge rate, the lower the cell capacity. Lower discharge rates result in higher capacity. Manufacturer's literature on batteries will normally specify several discharge rates (in amperes) along with the associated discharge time (in hours). The capacity of the battery for each of these various discharge rates can be calculated as already discussed [8, 9].

The rated capacity for lead-acid batteries is usually specified at the 8-, 10-, or 20-hour rates (C/8, C/10, C/20). UPS batteries are rated at 8-hour capacities and telecommunications batteries are rated at 10-hour capacities [16, 17].

In this work we adopt this principle in setting up a strategic Power management technique.

A flow chart on how energy is managed is shown in figure 4, battery consumption based on different mode is also shown, sleep, active when transmitting and receiving.

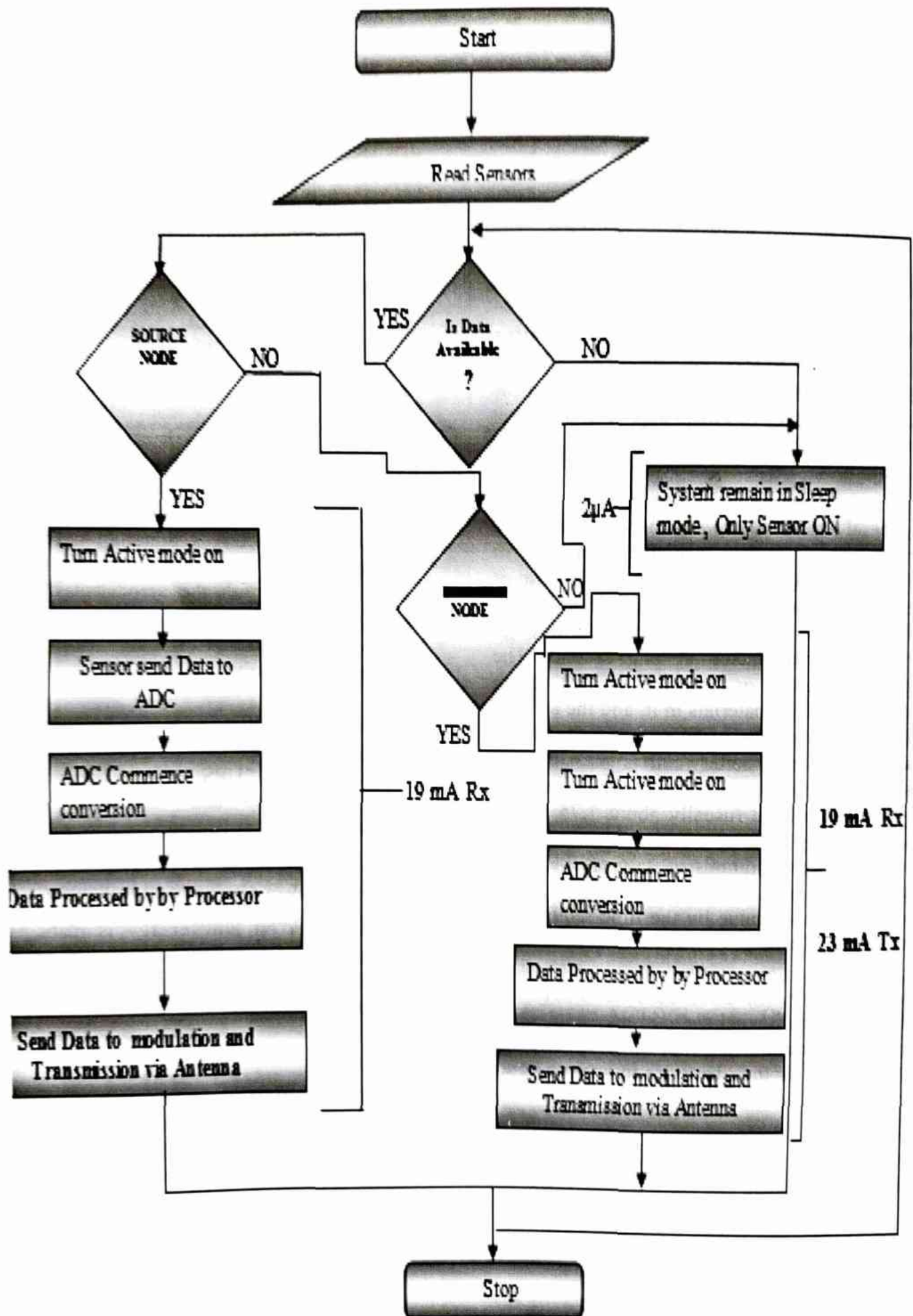


Figure 4: Flowchart for implementing energy saving technique

3.0 Energy Management Design Technique

We carry out an analysis on the length of time a battery can deliver for a continuous transmission. For mode of MRF let

$$Q = It$$

$$Q = AH$$

$$Q = \text{Charge}$$

$$A = \text{Ampere}$$

$$H = \text{Time}$$

$$IEEE\ 802.15.4 = 2.4GHz\ RF\ Transceiver$$

Low-Current Consumption:

RX mode: 19mA (typical)

TX mode: 23mA (typical)

Sleep mode: 2μA (typical)

Battery Rating

CHARGE = 1027 mAh

ENERGY = 3.8 Wh

VOLTAGE = 3.7V

Calculation of Network Life-Time

Reception Current 19 mA

Transmission Current 23 mA

Sleep Mode 0.002mA

$$\text{Total current} = 44.002\text{mA}$$

$$\text{Time} = \frac{1027}{44} \cong 23\ \text{Hours}$$

This calculation estimate the amount of current stored in the battery at different modes.

In figure 1, 50% of the energy is consumed while 50% is saved sampling time is divided by 2 as shown in figure 5 duty cycle, the circuit is made to sample for half the For a continuous battery usage the battery can stay for 23 hours.

Introducing *Sleep Mode Means Circuit* will sleep when there is no Transmission and Reception, the length a battery can stay when subjected to sleep and active is modeled from the test carried out as shown in time and also sleep in the second half, by this energy is conserved 50%.

If the time taken to sample temperature or CO is one milli second by sampling at 50% the time will conserve energy by half.

For Source nodes that requires 23mAh to transmit, since sampling time is halved, the battery ampere hour consumption becomes $23/2 = 11.5\ \text{mAh}$. Battery life can be conserved or extended for 50%

Figure 5 and figure 6 are time duty cycle time graphs showing the instances of figure 1, figure 2 and figure 3.

In Figure 6 about 90% of the energy is saved, while compared to figure 5.

We propose a conservative method to further extend Battery life if one could reduce the sampling time to 10% of the total time cycle, as shown in figure 2, 10% of the entire battery life is used while 90% is conserved. For a Source node, the ampere hour consumption becomes If the ampere hour consumption of the battery is 23mAh Then Conserved ampere hour value is 90% of 23 = 20.7 mAh as shown in figure 6 duty cycle..

Consumed or used ampere hour value is 10 % of 23 = 2.3 mAh.

When the node is in sleep, active node the ampere hour consumption is 2.3 mAh..

Though this come at a prize, as the variable to be measured can only be sampled one tenth of its period or cycled of availability. But we take consolation in the fact that the interval is happening at a very fast rate it can still measure the variable before it fades out.

For a full time active state of the node we carry out an analysis on the ampere hour consumption for the battery

When Source node is in active full mode it transmits the ampere hour consumption is 23 mAh for one hour.

For an intermediary node the ampere hour consumption is $23 + 19 = 42\ \text{mAh}$ for one hour when active and sleep mode 10% of 42 = 4.2 mAh

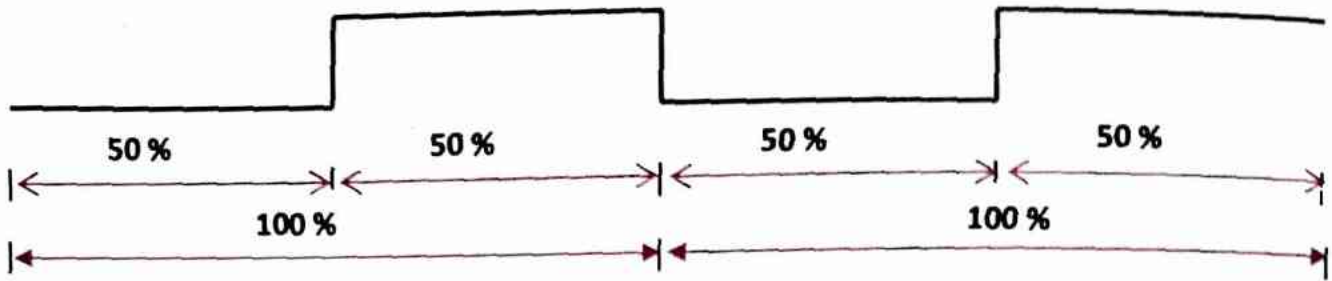


Figure 5 Graph of 50/50% Duty Cycle energy scheduling

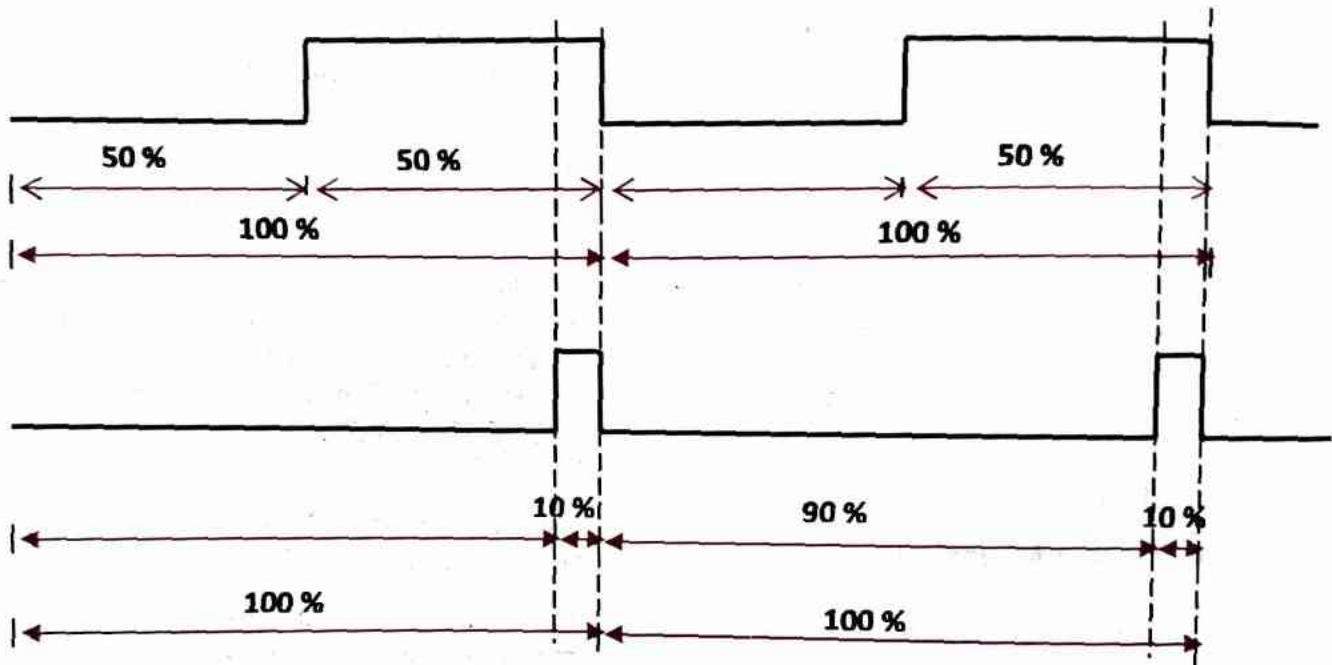


Figure 6 Graph of 10%/90% Duty Cycle time energy scheduling

For a full active mode the ampere hour consumption is

$23 + 19 = 42\text{mAH}$ for one hour when in full active mode. An equation that will represent the battery's response with respect to energy and time was evolved.

Let E = Ampere Hour consumption (AH)

T = time (t)

We adopt a linear method represented in equation (1)

$$\sum Y = a_0 N + a_1 \sum X \quad (12)$$

$$\sum XY = a_0 \sum X + a_1 \sum X^2 \quad (13)$$

$$a_0 = \frac{(\sum Y)(\sum X^2) - (\sum X)(\sum XY)}{N \sum X^2 - (\sum X)^2} \quad (14)$$

$$a_1 = \frac{N \sum XY - (\sum X)(\sum Y)}{N \sum X^2 - (\sum X)^2} \quad (15)$$

$$Y = a_0 + a_1 X \quad (16)$$

$$Y = a_1 X + a_0$$

$$X = b$$

$$a = a_0$$

$$n = 24$$

$$Y = E$$

$$b = a_1$$

$$E = a + bt \quad (17)$$

Source Sensor Node Sleep

$$N = 24$$

$$\sum t = 276$$

$$\sum tt = 4324$$

$$\sum Et = 280044$$

$$\sum E = 26398.185$$

Sensor Sleep/Active Mode

$$E = bt + a$$

$$a = \frac{(\sum E)(\sum t) - (\sum t) - (\sum E)}{N \sum t^2 - (\sum t)^2} \quad (18)$$

$$b = \frac{N \sum Et - (\sum t) - (\sum E)}{N \sum t^2 - \sum t^2} \quad (19)$$

$$\begin{aligned} a &= \frac{(26,398.185)(4324) - (276)(280044)}{24(4324) - (276)^2} \\ &= \frac{114145751.9 - 77292144}{103776 - 76176} \\ &= \frac{36853607.9}{27600} \\ a &= 1335.28 \end{aligned}$$

$$\begin{aligned} b &= \frac{(24)(280044) - (276)(26,398.185)}{(24)(4324) - 4324} \\ b &= \frac{6721056 - 7285899.06}{103766 - 4324} = \frac{-564843.06}{99452} \\ &= -5.67955 \cong -5.68 \end{aligned}$$

When $b = -5.68$ and $a = 1335.28$, then

$$E = 1335.28 - 5.68t$$

At $E_{\max} = 1027$ mAh (milli ampere hour)

The a battery can stay when subjected to sleep and active mode for 7.61 days

Sensor Source Node (Active Mode)

$$N = 24, b$$

$$\sum t = 274$$

$$\sum E = 23763.2718$$

$$\sum Et = 267545.465$$

$$\sum tt = 4324$$

$$E = bt + a$$

$$a = 1025.96$$

$$b = 19.05$$

$$E = -19.5t + 1025.96$$

For Intermediate Node In Sleep/Active Node

$$n = 24$$

$$\sum t = 274$$

$$\sum E = 22779.074$$

$$\sum Et = 268985.898$$

$$\sum t^2 = 4324$$

$$E = bt + a$$

$$a = 1022$$

$$b = 4.081$$

Sleep/Active Mode

$$n = 24$$

$$\sum t = 274$$

$$\sum t^2 = 4324$$

$$\sum E = 24353.493$$

$$\sum Et = 278496.8746$$

$$b = -1909.02$$

$$E = 2.154t + 863.92 \quad (20)$$

$$E = 2.81t + 1022 \quad (21)$$

$$E = -4.08t + 1022.7 \quad (22)$$

$$E = -25.08t + 1023.7 \quad (23)$$

Equations 20, 21, 22 and 23 are models for energy demands in Ah/Time for Source node when in sleep mode, active and Intermediary node when in sleep and active modes.

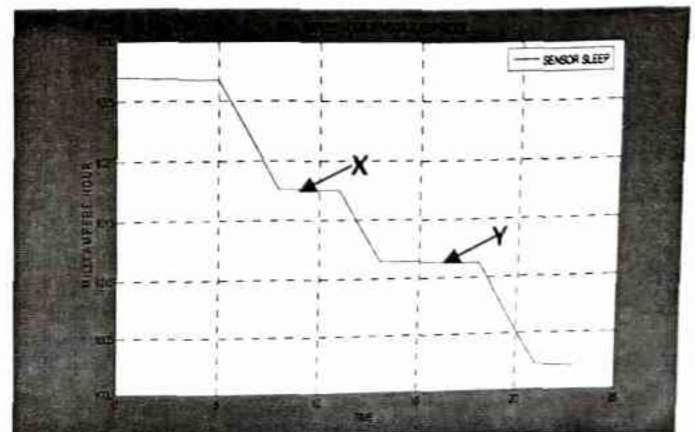


Figure 7 Source Node Sleep/Active

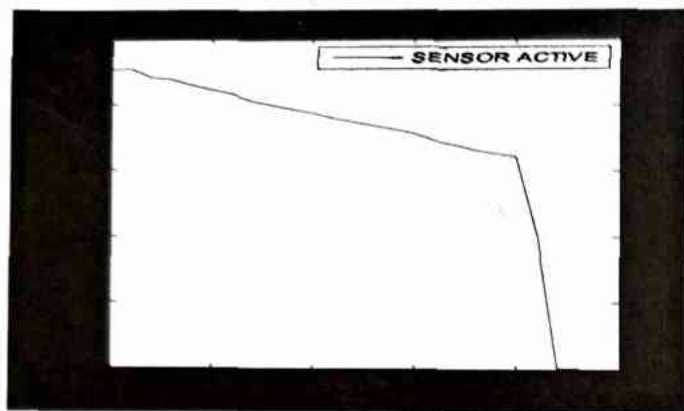


Figure 8 graph of source active

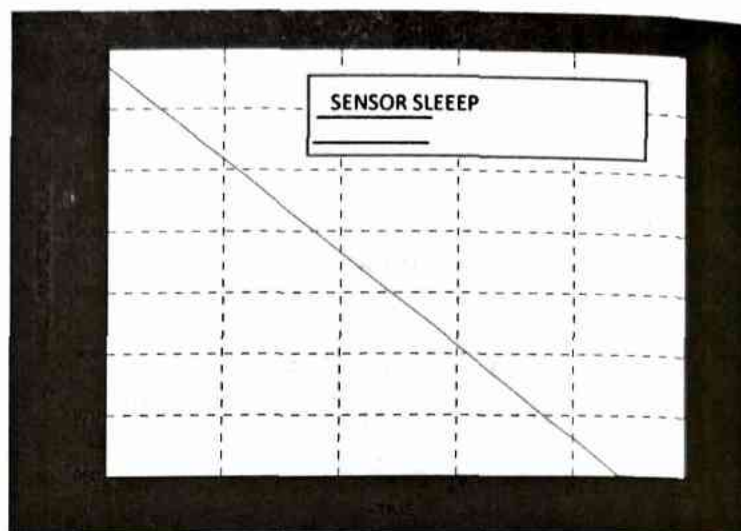


Figure 11 Intermediary Node Active

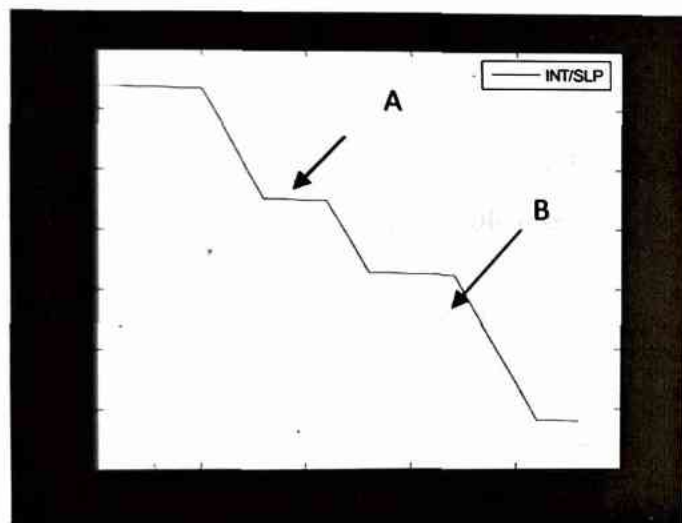


Figure 9 intermediary node sleep mode

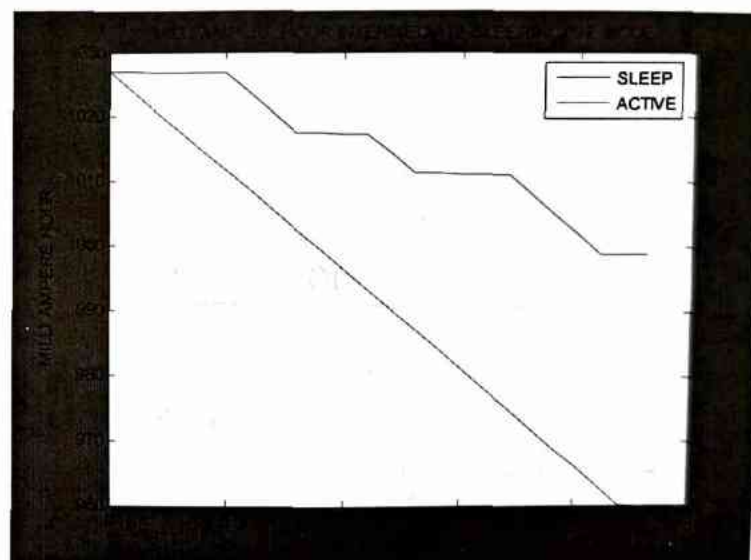


Figure 12: Intermediary Node Sleep Active

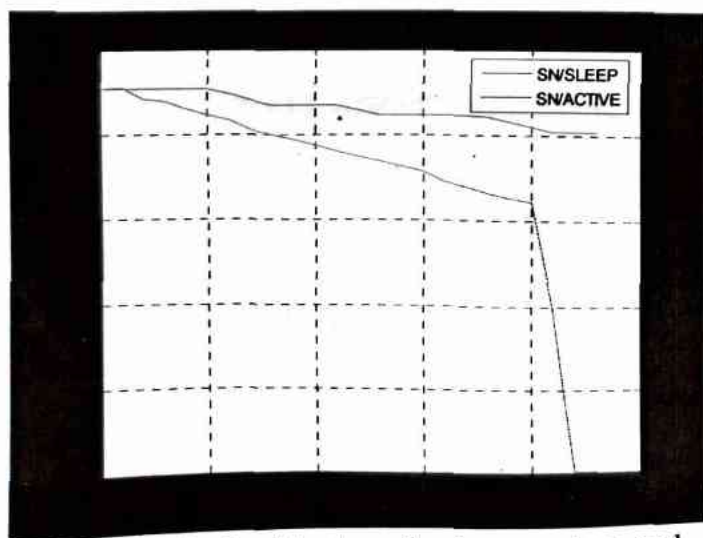


Figure 10: Combined graph of source sleep and active mode

4.0 Discussion of Result

Graph in figure 7 is a result of ampere hour consumption when source node can be made to sleep and also go active so as to conserve battery, point X is the active period while point Y is the sleep period.

Graph in figure 8 is a result of ampere hour consumption when source node is made to monitor all through without going to sleep, the consumption rate is high and the difference can be seen when we compare

Graph in figure 9 is a result of ampere hour consumption of intermediary node when it is made to sleep and wake up. That is, it can go off

and on, so as to conserve battery. Point X is the active period while point Y is the sleep period which is the 50% trade off earlier mentioned.

Figure 10 is a comparison of the source node when in active state and also when it goes to sleep .

Figure 11 is a graph showing result of intermediary node energy ampere hour consumption.

In all it can be deduced that when no data is available to be read the node goes to sleep and energy is conserved, but when in permanent active mode ,whether there is data to be read or not the node is permanently kept ON, and due to the consistent ON state energy is ,therefore reducing battery life. When fully charged, the battery has an ampere hour value of 1027 mAH as in figure 8. When subjected to sleep and active mode for 24 hours, the ampere hour value of the battery fell to 998 mAH for source node and 900 for mAH for intermediate nodes.

5.0 Conclusion

In this paper we proposed a scheme that is based on pre-emptive time scheduling called duty circle for managing energy in a wireless sensor network , the goal of the proposed scheme is to ultimately extend the network life-time , to achieve this goal the proposed scheme consist of 3 parts namely Energy saving mode 2 Energy saving mode2 and hybrid mode. with the hybrid mode as the best and smartest option.

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