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EXPERIMENTAL ANALYSIS OF WSN COMMUNICATION ENERGY USING TELOSB SENSOR NODES

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Abstract

One of the major design issues for a sensor network is conservation of the energy available at each sensor node. Energy is a cost metric and therefore needs to be minimized when deploying and developing wireless sensor network (WSN). This paper presents the statistical analysis of energy expended in transmitting and receiving of data in WSN. The aim of this paper is to analyse the energy expended by TelosB sensor nodes during transmission and forwarding of data in a WSN. This was done to estimate the network life time of the wireless sensor network built. A WSN test bed comprising of four TelosB sensor nodes was built at the library field of Nnamdi Azikiwe University, Awka. Three of the sensor nodes were placed at angles and the remaining one was attached to a laptop and used as the sink. Extensive measurements of RSSI were taken at distances of 5m to 60m at the interval of 5m. Channel prediction model of the environment was developed from the measured data using Linear Regression Analysis. The values of the pathloss exponent and standard deviation obtained are 2.67, 2.3dB respectively. The energy spent in transmission, reception and forwarding of data during the experiment was calculated using first order radio energy model equation. Least Mean Square Error method of Linear Regression Analysis was used to develop a model of the transmission and forwarding energy of the WSN. The R^2 the goodness of fit of the model was determined to be 0.93 and 0.96 for transmission and forwarding energy respectively. This confirms that the models can generally be applied in Energy determination of an environment with similar radio characteristics.

Index words: pathloss, TelosB sensor nodes, WSNs

I. INTRODUCTION

A Wireless Sensor Network (WSN) consists of a large number of tiny sensor nodes deployed over a geographical area called sensing field. Each node is a low power device that integrates computing, wireless communication and sensing abilities [1, 2]. Wireless Sensor Networks (WSNs) are applied in various areas. A Wireless Sensor Network can be viewed as an intelligent distributed measurement technology adequate for many different monitoring and control context. In recent years, the number of sensor network deployments for real life applications such as environmental monitoring [3], agriculture [4], production and delivery [5], military [6], structural monitoring [7] and medical applications [8] has rapidly grown tremendously.

However energy consumption still remains one of the main obstacles to the diffusion of this technology, especially in application scenarios where a long network life time and a high quality of service are required. Nodes are generally powered by batteries which have limited capacity and, often can neither be replaced nor recharged due to environmental constraints. Energy is a limited resource and must be used judiciously despite the fact that energy scavenging mechanisms can be adopted to recharge batteries [9]

Energy conservation is very important in Wireless Sensor Network and so the use of low power transceivers in the communication unit of the sensor nodes is adopted. Routing is responsible for almost all the energy consumption in WSN and therefore sensing energy is negligible since it is very minute compared to energy spent in communication. As a result, energy efficient routing algorithm is very important for continuous and efficient communication. In a multihop ad hoc sensor network, each node plays the dual role of data originator and data router. The malfunctioning of few nodes can cause significant topological changes and might require re-routing of packets and re-organization of the network. Hence, energy conservation and power management are very important in WSN[10].

In the experiment TelosB sensor nodes was used. The TelosB sensor node by crossbow is an IEEE 802.15.4/ Zigbee compliant node [11]. The nodes are composed of four main units namely; the Chipcon CC2420 transceiver, the MSP430 microcontroller, the power section which consists of two AA (3V) batteries and the sensor section which consists of temperature (-40-123.8^{o}c), humidity (0-100%RH), visible light (320nm-730nm) sensors and slot for any two sensors of one's choice. An IEEE 802.15.4 compliant radio can operate in 16 channels in the 2450MHz ISM band, 10 channels in the 915MHz band (only in the US) and 1 channel in the 868MHz band (EU and Japan). The 2450MHz band allows higher data rate and offers more channels than the other bands and thus is suitable for sensor networks with high network load. Signaling in the 2450MHz band is based on Orthogonal Quadrature Phase Shift Keying (OQPSK) and Direct Sequence Spread Spectrum (DSSS). The CC2420 integrated circuit (IC) implements the 2450GHz physical layer (PHY) and supports Medium Access Control (MAC) functionalities. The transmitter and receiver have respectively a direct up conversion and low IF Inphase/Quadrature (I/Q) architecture. The chipcon CC2420 transceiver has 250kbps data rates, RF power of -24 to 0dBm, receive sensitivity of -90 to -94dBm.

To be able to assess the average power consumption of an IEEE 802.15.4 node in a network it is necessary to characterize the instantaneous power consumption of the transceiver when operating in and switching between states [12]. The CC2420
transceiver supports four states: Shutdown state in which the clock is switched off and the chip is completely deactivated waiting for a start up strobe, The Idle state in which the clock is turned on and the chip can receive commands (for example, to turn on the radio circuitry), the Transmit and Receive states. In the context of wireless microsensor networks, which are characterized by a very low transmission duty cycle, it has been shown that the transient energy when switching from one mode to another significantly impacts the total power consumption [13,14]

II. LITERATURE REVIEW

Wireless microsensor network research in recent years has strived to design radio circuitry and transmission protocols to meet these novel constraints [15,16] and it is expected that results from this research will soon emerge in industrial applications. An important milestone in this transition has been the release of the IEEE 802.15.4 standard [17] that specifies interoperable physical and medium access control layers targeted to sensor node radios. In [18], the performance of the 802.15.4 standard in terms of throughput and energy efficiency is assessed based on simulation. However, this work focuses on a scenario with few nodes and low load, which diverges significantly from the conditions encountered in wireless microsensor networks. In [12], the authors evaluated the potential of the IEEE 802.15.4 standard for use in an ultra low power sensor node operating in the aforementioned dense network conditions. A detailed survey on several energy management schemes was done by the authors in [19]. Most of the several energy schemes proposed in the literature assumes that data acquisition and processing have energy consumption significantly lower than communication and so they are targeted at minimizing the radio activity. The authors also surveyed the strategies for reducing the power consumption acting at the radio level. In [20], the authors explained that because of the increasing exploitation of sensor networks for monitoring complex phenomena that the above assumption in reference 24 does not hold in many practical applications scenarios, mainly due to specific sensors whose power consumption cannot be neglected. The authors in [21] classified and reviewed the main approaches proposed for energy management at the sensor level. They also explained that energy savings can be obtained by acting at the unit, cluster and network levels, for instance by considering data compression and aggregation, predictive monitoring, topology management and adaptive duty cycle.

In the next Section, the methodology adopted in the research was explained. The measurement taken was recorded and evaluated using the first order radio energy equation. In section 4, the data obtained was analysed, the result was evaluated and discussed.

III. RESEARCH METHODOLOGY

This paper presents statistical analysis of energy of wireless sensor nodes in an outdoor environment. Extensive real time measurements of received signal strengths were done in the testbed. The aim of the experiment is to determine the transmission, reception and forwarding energies of the sensor nodes. A testbed consisting of four crossbow TelosB sensor nodes from Texas Instrument was built at the Library field of Nnamdi Azikiwe University, Awka. The sensor nodes were programmed with Java and *NesC* programming language. The nodes are programmed to send data every 5 seconds. The data collected over a long period of time was averaged and used for the analysis.

The measurements were taken from 5m to 60m at the interval of 5m, the reference distance d_o is 1m. The mean value of the RSSI obtained at a given distance was calculated. The testbed environment was characterized and pathloss prediction parameters were obtained using the log-normal shadowing model. The path loss prediction parameters obtained reveals that the path loss exponent value and the standard deviation caused by the shadowing effect are 2.67, 2.3dB respectively. The analysis was done using first order radio model. The diagram is shown in figure 1 [20].

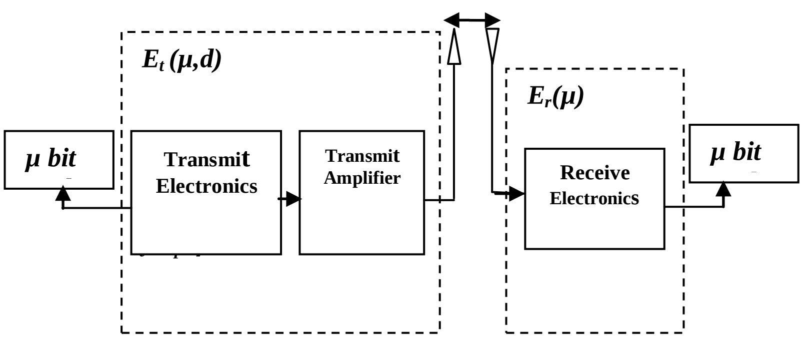

Figure 1: Radio Energy model diagram

The first order radio energy model states that the energy consumed by the transmitter and the receiver of WSN can be modeled respectively as [20]:

$$E_t(\mu,d) = \mu(\ell_t + \varsigma d^n) \qquad (1)$$

$$E_r(\mu) = \mu\ell_r \qquad (2)$$

where E_t, E_r are the transmission and reception energies respectively, μ denotes the number of bits, ℓ_t and ℓ_r are energy per bit consumed in the transmitter and receiver respectively. ς accounts for the energy dissipated in the transmit amplifier and *d* is the distance between the transmitter and the receiver. *n* is the pathloss exponent which ranges between 2 and 4. It is closer to 2 if there is a perfect line of sight between the transmitter and receiver and can go up to 4 in dense urban areas. The radio parameters are given as $\ell_e = 50 nanoJ/bit$, $\varsigma_{fs} = 10 picoJ/bit/m^2$, $\varsigma_{mp} = 0.0013 picoJ/bit/m^4$.. where ℓ_e denotes the energy of the electronics, ς_{fs} is the energy dissipated in the amplifier when there is free space or near free space transmission, ς_{mp} is the energy dissipated when the transmission is multipath. $\ell_t = \ell_r = \ell_e$, since the transmitter and the receiver have the same communication circuitry. The energy determination was done for free space, the testbed and multipath for comparison purposes.

For free space transmission

$$E_t(d) = \{\mu\ell_e + \mu\varsigma_{fs} d^2 \qquad (3)$$

And for multipath transmission

$$E_t(d) = \{\mu\ell_e + \mu\varsigma_{mp} d^4 \qquad (4)$$

The amount of Energy to forward this message for free space and multipath transmissions were shown in equation 5 and 6 respectively

$$E_f = 2\mu\ell_e + \mu\varsigma_{fs} d^2 \qquad (5)$$

$$E_f = 2\mu\ell_e + \mu\varsigma_{mp} d^4 \qquad (6)$$

From the experiment carried out the pathloss exponent were calculated as 2.67 for testbed. Thus the energy dissipated by the transmitter to run the radio electronics and the amplifier for the testbed is given in equations 7.

$$E_t(d) = \{\mu\ell_e + \mu\varsigma_{fs} d^{2.67} \qquad (7)$$

Also the energy needed to forward the message using the calculated pathloss for the testbed is:

$$E_f = 2\mu\ell_e + \mu\varsigma_{fs} d^{2.67} \qquad (8)$$

When an event is detected by the source node, it will send a μ bits message through either direct or multi-hop transmission to the remote sink node. Since multi-hop transmission is more energy efficient when d is large, hence the N – hop transmission from source to sink node is chosen. Based on Equations 7 and 8, the total energy consumption, E_N, to transmit one bit data ($\mu = 1$) over N-hop route will be

$$E_N = \sum_{i=1}^{N} \left(\ell_e + \varsigma d_1^n\right) + \sum_{i=2}^{N} \ell_e \qquad (9)$$

$$E_N = \ell_e + \varsigma d_1^n + \sum_{i=2}^{N} \left(2\ell_e + \varsigma d_1^n\right) \qquad (10)$$

where $\varsigma = \varsigma_{fs}$ when n=2 and $\varsigma = \varsigma_{mp}$ when n=4

$$\therefore E_N = (2N-1)\ell_e + \sum_{i=1}^{N} \varsigma d^n \qquad (11)$$

For the same distance between nodes $\sum_{i=1}^{N} d_i = d$, $\sum_{i=1}^{N} d_i$ has a minimal value when $d_1 = d_2 = \dots d_n = H/n$.

Since the distance d_i as well as the traffic length is the same for all sensor nodes, the sensor nodes consume energy at the same rate. Hence,

$$\ell_1 \approx \ell_2 \approx \ell_3 \cdots \approx \ell_N$$

Equations 2, 7 and 8, are used to calculate the reception, transmission and forwarding energies of the testbed. In the experiment, 16 bytes was used which is equal to 128bits. For example to calculate the reception, transmission and forwarding energies at distance of 1m and 5m;

$$E_r = 128 \times 50 \times 10^{-9} = 6400 \times 10^{-9} J \quad = 6.4 \times 10^{-6} J \quad = 6.4\mu J$$

At 1m

$$E_t = 128 \times 50 \times 10^{-9} + 128 \times 10 \times 10^{-12} \times 1^{2.67} = 6400 \times 10^{-9} + 1280 \times 10^{-12} = 6.401\mu J$$

$$E_f = 2 \times 128 \times 50 \times 10^{-9} + 128 \times 10 \times 10^{-12} \times 1^{2.67} = 12800 \times 10^{-9} + 1280 \times 10^{-12} = 12.801\mu J$$

At 5m

$$E_t = 128 \times 50 \times 10^{-9} + 128 \times 10 \times 10^{-12} \times 5^{2.67} = 6400 \times 10^{-9} + 94071.89 \times 10^{-12} = 6.491\mu J$$

$$E_f = 2 \times 128 \times 50 \times 10^{-9} + 128 \times 10 \times 10^{-12} \times 5^{2.67} = 12800 \times 10^{-9} + 94071.89 \times 10^{-12} = 12.894\mu J$$

and so on.

Also the reception, transmission and forwarding energies of the free space and multipath model are calculated in the same way with the pathloss exponent of 2 and 4 respectively. The reception energy is the same at all distance because it is independent of distance. The values obtained are shown in Table 1. Graphs are plotted using Matlab to show the rate of depletion of energy with distance for the testbed. Also graphs showing the relationship between the three energy model in terms of the transmission, reception and forwarding energies were plotted.

Table 1: Energy dissipation of the testbed, free space and multipath model of the testbed (Energy is in μJ and distance in meters)

Distance	E_{Tf}	E_{Tp}	E_{Tm}	E_{Rfpm}	E_{Ff}	E_{Fp}	E_{Fm}
1	6.40	6.40	6.40	6.4	12.80	12.80	12.80
5	6.42	6.49	7.20	6.4	12.83	12.89	13.60
10	6.53	7.00	19.20	6.4	12.93	13.40	25.60
15	6.69	8.17	71.20	6.4	13.09	14.57	77.60
20	6.91	10.21	211.20	6.4	13.31	16.61	217.60
25	7.20	13.31	506.40	6.4	13.60	19.71	512.80
30	7.55	17.65	1043.20	6.4	13.95	24.05	1049.60
35	7.97	23.38	1927.20	6.4	14.37	29.78	1933.60
40	8.45	30.65	3283.20	6.4	14.85	37.05	3289.60
45	8.99	39.61	5255.20	6.4	15.39	46.01	5261.60
50	9.60	50.40	8006.40	6.4	16.00	56.80	8012.80
55	10.27	63.15	11719.20	6.4	16.67	69.55	11725.60
60	11.01	77.99	16595.20	6.4	17.41	84.39	16601.6

Energy is in μJ and distance in meters. E_{Tp}, E_{Fp} is the transmission and forwarding energy of the testbed, E_{Tf}, E_{Ff} is the transmission and forwarding energy of the free space model, E_{Tm}, E_{Fm} is the transmission and forwarding energy of the multipath model and E_{Rpfm} is the reception energy of all the three models. Since the energy dissipated in the receiver is distance independent but depends only on the receiver electronics, the three models have the same reception energy at all distances.

IV. DATA ANALYSIS AND RESULT DISCUSSION

The Matlab software tool was used to plot the transmission, reception and forwarding energies of the testbed as shown in Figure 2.

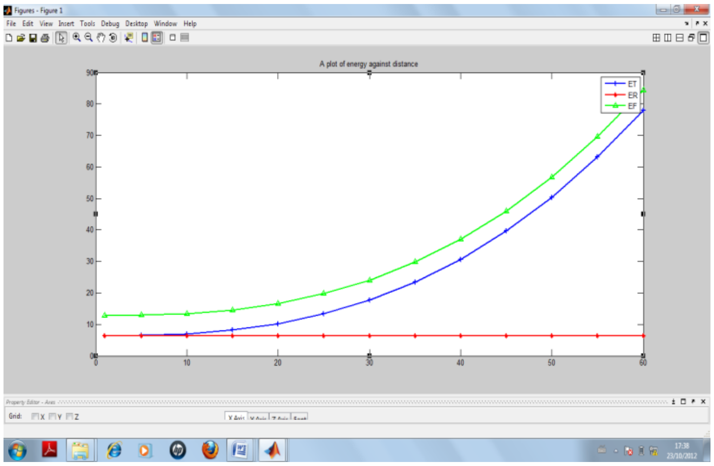

Figure 2: A graph showing the transmission, reception and forwarding energy of the testbed

The Transmission and Forwarding energy of the testbed was linearised and a model equation of the energy was developed as shown in Equations 12 and 13 respectively. The graphs of the models are shown in Figures 3 and 4 respectively.

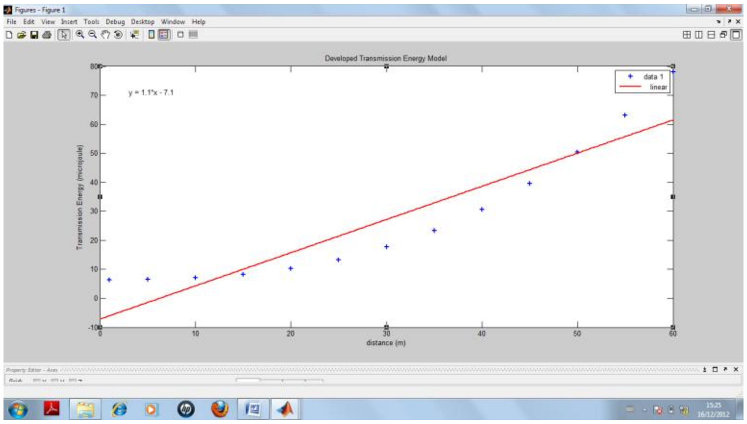

Figure 3: Plot of the model of the transmission energy of the testbed

The Transmission energy of the testbed follows the trend given by equation 12.

$$E_t = 1.1 * d - 7.1 \qquad (12)$$

where d is the distance

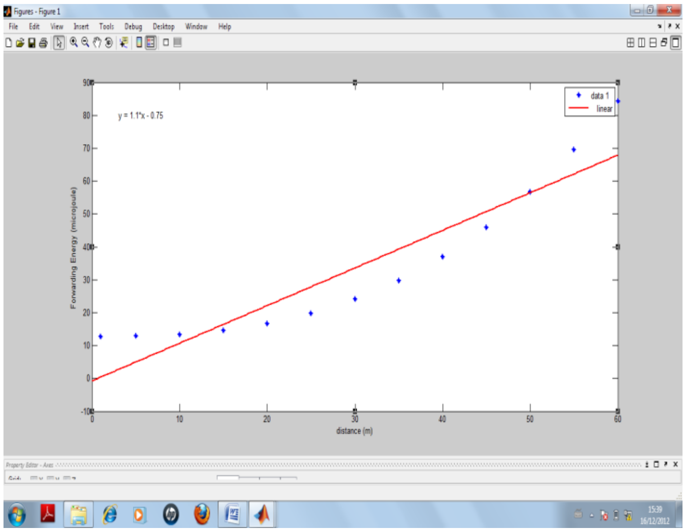

Figure 4: Plot of the model of the Forwarding energy of the testbed

The Forwarding energy in testbed follows the trend given by equation 13.

$$E_f = 1.1 * d - 0.75 \qquad (13)$$

The goodness of fit (R^2) of the Transmission and Forwarding Energy models developed for the testbed was tested and found to be 0.93 and 0.96 respectively. This confirms that the models can generally be applied in Energy determination of an environment with similar radio characteristics. Therefore, the Transmission and Forwarding Energies at any known distance can be calculated using the developed model of Equations 12 and 13 respectively for the outdoor testbed. Also graph of the transmission and forwarding energies of free space, the testbed and multipath scenario were plotted in figures 7 and 8 respectively. From the graph it was observed that the free space has minimal energy consumption both for transmission and forwarding of data followed by the testbed environment. it was observed that there is much deviation of both transmission and forwarding energy in the multipath situation. This is due to the high pathloss exponent in multipath transmission.

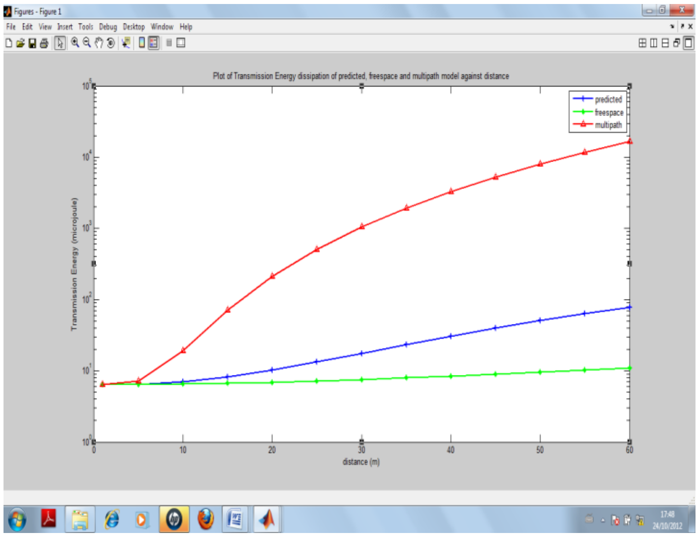

Figure 5: A graph of transmission energy of the testbed, free space and multipath model against Distance

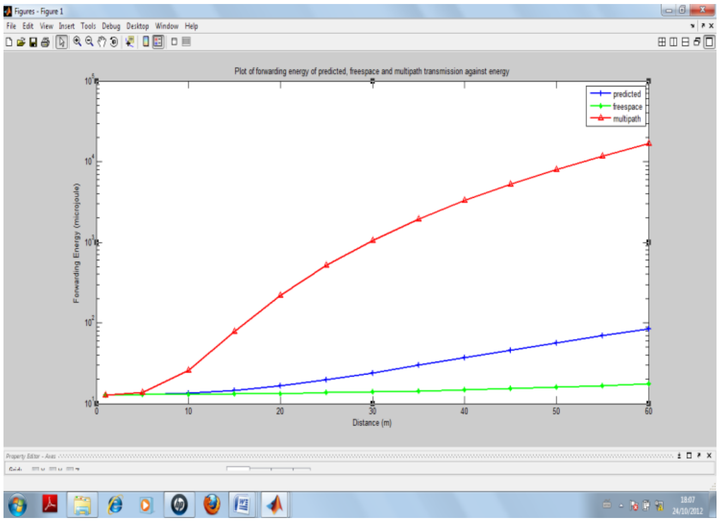

Figure 6: A graph of forwarding energy of the testbed, multipath and free space model against Distance

V. CONCLUSION

Energy conservation is very important in WSN to prolong the life time of the nodes.Real time field measurement was done at the library field of Nnamdi Azikiwe University, Awka. The result of the measurement was analysed. The transmission, reception and forwarding energies of the sensor nodes were calculated. A model of the transmission and forwarding energies was developed. The goodness of fit (R^2) of the Transmission and Forwarding Energy models developed for the testbed was tested and found to be 0.93 and 0.96

respectively. This confirms that the models can generally be applied in Energy determination of an environment with similar radio characteristics.

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