Theoretical versus Practical Results of an Advanced Power Model used in Communications of Wireless Sensor Networks

Abdelrahman Elleithy, Gonhsin Liu, and Varun Pande

***Abstract*—in this paper we present an advanced model for power consumption in communications. The new model for power consumed in communications takes into consideration parameters power consumption for the active mode, power consumption for the sleep mode, power consumption for the transient mode, transmission period, transient mode duration, sleep mode duration, and active mode duration. The new model for power consumption in communications has been tested versus a network of Micaz sensors and it shows results within 5% difference between theoretical and practical results. The results obtained in this paper are more accurate than those previously published.**

Keywords: Wireless Sensors Networks, Network Lifetime, Models, Simulation

I. A Model For Lifetime Of Wireless Sensors Networks

Wireless sensors have received increased attention in the past years due to their popularity and cost effectiveness when they are used in harsh environments. They have been used in many applications including military applications, environmental applications, health applications, and home applications. Although they are very cost effective and easily deployed in harsh environments, they are limited by the power available through their life cycle. Sensors are usually deployed with limited power which is depleted over their life cycle. Once their power is depleted, the sensors become dead and they are no more useful. An evaluation of the life cycle of a wireless sensor network is very essential to estimate how long a network can live and when the network and its sensors might be replaced or recharged if possible.

In this section we present a model for the lifetime of Wireless sensor networks based on a paper by [1]. The model takes different parameters that are used in literature. The following parameters are considered:

1. The time until the first sensor is drained of its energy [2];
2. The time until the first cluster head is drained of its energy [3];
3. The time there is at least a certain fraction β of surviving nodes in the network [4];
4. The time until all nodes have been drained of their energy [5];
5. K-coverage: the time the area of interest is covered by at least k nodes [6];
6. 100% coverage
   a. The time each target is covered by at least one node [7];
   b. The time the whole area is covered by at least one node [8];
7. α-coverage
   a. The accumulated time during which at least α portion of the region is covered by at least one node [9];
   b. The time until the coverage drops below a predefined threshold α (until last drop below threshold) [10] ;
   c The continuous operational time of the system before either the coverage or delivery ratio first drops below a predefined threshold [11];
8. The number of successful data-gathering trips [12];
9. The number of total transmitted messages [13];
10. The percentage of nodes that have a path to the base station [11];
11. Expectation of the entire interval during which the probability of guaranteeing connectivity and k-coverage simultaneously is at least α [6];
12. The time until connectivity or coverage are lost [14];
13. The time until the network no longer provides an acceptable event detection ratio [5];
14. The time period during which the network continuously satisfies the application requirement [15];
15. The minimum of t_1, t_2, and t_3 with t_1: time for cardinality of largest connected component of communication graph to drop below $c_1 \times n(t)$, t_2: time for n(t) to drop below $c_2 \times n$, t_3: time for the covered volume to drop below $c_3 \times ld$ [16].

II. Parameters Used In The Model

In this section we address parameters that were introduced in literature that can be used in a complete model for a wireless sensors networks lifetime. In earlier version of this model was introduced by Elleithy and Liu [17]. The following parameters are introduced:

Manuscript received February 9, 2014.
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978-1-4799-5233-5/14/$31.00 ©2014 IEEE

1. The total number of available sensors
2. The set of all nodes those that are alive at time t
3. The set of nodes those that are active at time t
4. The set of nodes those that are active at any time in the time interval [t −Δt, t]
5. The set of sink nodes or base stations B(t) is defined to be a subset of the existing nodes SY
6. The ability of nodes m1 and m_n to communicate at a time t
7. The ability of two nodes to communicate in the time interval [t −Δt, t] such that the links between consecutive hops become available successively within the time interval (support for delay tolerant networking)
8. The set of target points to be sensed by the network
9. The area that is covered by all sensors of a certain type y, at a time t.

III. A NEW MODEL OF POWER CONSUMPTION IN COMMUNICATIONS OF WIRELESS SENSOR NETWORKS

In this section we present a new model for the power consumption of the communications in wireless sensor networks. The model is based on the work of Cui *et. al.* [18].

In this model, the total energy consumed in communications is given by Equation (1):

$$E = P_{on}T_{on} + P_{sp}T_{sp} + P_{tr}T_{tr} = (P_t + P_{c0})\, T_{on} + P_{sp}T_{sp} + P_{tr}T_{tr} \quad (1)$$

The following parameters are used in the calculation of Equation (1):

1. P_{on} power consumption value for the active mode
2. P_{sp} power consumption value for the sleep mode
3. P_{tr} power consumption value for the transient mode
4. the transmission period: T is given by $T = T_{tr} + T_{on} + T_{sp}$,
5. T_{tr} is the transient mode duration, which is equal to the frequency synthesizer settling time (the start-up process of the mixer and PA is fast enough to be neglected),
6. T_{sp} is the sleep mode duration,
7. T_{on} is the active mode time for the transceiver such that $T_{on} \le T$, where T_{on} is a parameter to optimize,
8. The active mode power P_{on} comprises the transmission signal power P_t and the circuit power consumption P_{c0} in the whole signal path.
9. P_{c0} consists of the mixer power consumption P_{mix}, the frequency synthesizer power consumption P_{syn}, the LNA power consumption P_{LNA}, the active filter power consumption P_{filt} at the transmitter, the active filter power consumption P_{filr} at the receiver, the IFA power consumption P_{IFA}, the DAC power consumption P_{DAC}, the ADC power consumption P_{ADC}, and the PA power consumption P_{amp}
10. $P_{amp} = \alpha\, P_t$ and $\alpha = \xi/\eta - 1$ with η the drain efficiency [18] of the RF PA and ξ the peak-average ratio (PAR), which is dependent on the modulation scheme and the associated constellation size.
11. Since $P_{on} = \max\{\, P_{on}, P_{tr}, P_{sp} \,\}$, the peak-power constraints are given by:

$$P_{ont} = P_t + P_{amp} + P_{ct} = (1+\alpha)P_t + P_{ct} \le P_{maxt}$$

$$P_{onr} = P_{cr} \le P_{maxr}$$

12. $P_{ct} = P_{mix} + P_{syn} + P_{filt} + P_{DAC}$ and $P_{cr} = P_{mix} + P_{syn} + P_{LNA} + P_{filr} + P_{IFA} + P_{ADC}$ denote the circuit power consumption (excluding the PA power consumption) in the active mode at the transmitter and the receiver, respectively.
13. The start-up time for other circuit blocks is negligible compared to that of the frequency synthesizers.
14. Given (1) and (2), and the fact that $P_{sp} = 0$and $P_{tr} \approx 2\, P_{syn}$, the energy consumption per information bit $E_a = E/L$ is given by
15. $E_a = [(1 + \alpha)P_tT_{on} + P_cT_{on} + P_{tr}T_{tr}\,]/\,L \approx [(1 + \alpha)E_t + P_cT_{on} + 2\, P_{syn}\, T_{tr}\,]/\,L$
16. $B_e = L/(BT_{on})$ (in bits per second per hertz).

IV. THEORETICAL VERSUS PRACTICAL RESULTS

A. Parameters used in the proposed model

The following parameters values are used in theoretical and practical tests carried in this paper:

k = 3.5 // Path loss exponent

G1 = 1000 Watt // gain factor at distance = 1 meter [Amplifier]

B = 10 KHz// Bandwidth[transmission channel]

Pmix = 30.3 mW // mixer power consumption [Transmitter, Receiver]

PLNA = 20 mW // Low noise amplifier power consumption [Receiver]

Pmaxt = 250 mW // maximum power available for transmitter signal path

Ttr = 5 micro-second // transient mode duration

T = 0.1 second// transmission period

Nf = 10 Watt// receiver noise figure

drainEfficiency = 0.35 // drain efficiency [Power Amplifier of Transmitter]

psdensity = 3.881*10-21 W per Hz// power spectral density [Receiver AWGN]

L = 2 Kbit// packet size

Psyn = 50 mW// frequency synthesizer power consumption [Transmitter, Receiver]

PIFA = 3 mW// Intermediate frequency amplifier power consumption [Receiver]

Pfilt = 2.5 mW// active filter power consumption [Transmitter]

Pfilr = 2.5 mW// active filter power consumption [Receiver]

Ml = 10000 Watt// link margin [Amplifier parameter compensating

hardware variations and background noise]

Pb = 0.001// probability of bit error

Vdd = 3 Volt// power supply [ADC, DAC]

Lmin = 0.5 micrometer// minimum channel length [Receiver Technology]

n1 = 10// number of current sources [DAC]

n2 = 10 // Effective number of bits [ADC]

fcor = 1 MHz// corner frequency of noise [ADC , DAC]

I0 = 10 microampere// current source [DAC]

Cp = 1 picofarad// parasitic capacitance [DAC]

beta = 1// correcting factor [DAC]

B.Results

In this section, the results of the power consumption in communications where the total energy per bit is calculated versus time spent on the On mode for different parameters are given. We are comparing the results obtained from our mathematical model with results obtained from Micaz sensors simulation.

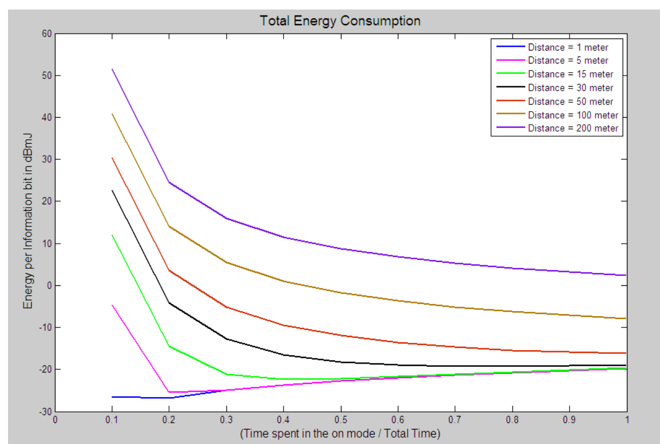
Figure 1 shows the Total Energy Consumption per bit versus Time Spent in the On mode/ Total Time for different distances at a packet size of 2000 bits. The figure shows the energy consumption from 1 meter to 200 meters. As the distance of transmission increases, the total energy per bit increases. Also, as the time Spent in the On mode/ Total Time increases, the energy per bit decreases. Finally, a comparison between the results obtained from the mathematical model in part (a) versus the results obtained from the simulation of the Micaz sensors show that the accuracy of the results are within 5%.

Figure 2 shows the Total Energy Consumption per bit versus Time Spent in the On mode/ Total Time for different packet size for a path loss exponent of 3.5 and a distance of 30 meters. As the packet size increases, the total energy per bit increases. Also, as the time spent in the On mode/ Total Time increases, the energy per bit decreases. Finally, a comparison between the results obtained from the mathematical model in part (a) versus the results obtained from the simulation of the Micaz sensors show that the accuracy of the results is within 5%.

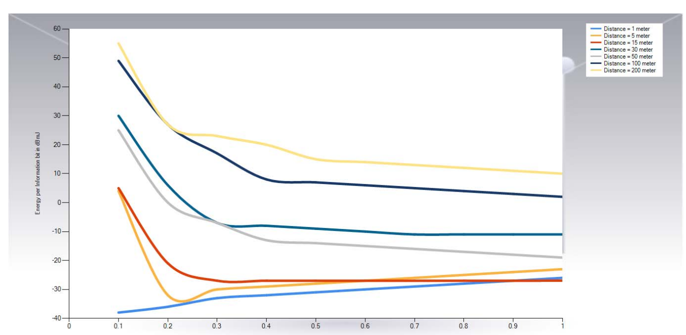
Figure 3 shows the Total Energy Consumption per bit versus Time Spent in the On mode/ Total Time for different path loss exponent (K) at a packet size of 2000 bits and a distance of 30 meters. As the path loss exponent increases, the total energy per bit increases. Also, as the time spent in the On mode/ Total Time increases, the energy per bit decreases. Finally, a comparison between the results obtained from the mathematical model in part (a) versus the results obtained from the simulation of the Micaz sensors show that the accuracy of the results is within 5%.

Figure 4 shows the Total Energy Consumption per bit versus Time Spent in the On mode/ Total Time for different bandwidth at a packet size of 2000 bits and a distance of 30 meters. As the bandwidth decreases, the total energy per bit increases. Also, as the time spent in the On mode/ Total Time increases, the energy per bit decreases. Finally, a comparison between the results obtained from the mathematical model in part (a) versus the results obtained from the simulation of the Micaz sensors show that the accuracy of the results is within 5%.

Figure 5 shows the Total Energy Consumption per bit versus Time Spent in the On mode/ Total Time for different drain efficiency at a packet size of 2000 bits and a distance of 30 meters. As the drain efficiency decreases, the total energy per bit increases. Also, as the time spent in the On mode/ Total Time increases, the energy per bit decreases. Finally, a comparison between the results obtained from the mathematical model in part (a) versus the results obtained from the simulation of the Micaz sensors show that the accuracy of the results is within 5%.

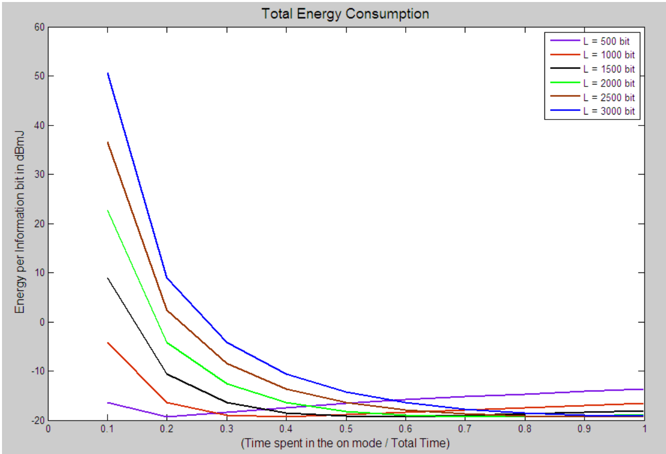


(a)Results obtained from the mathematical model

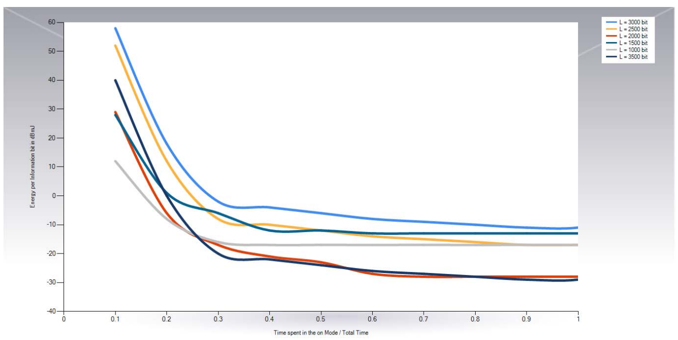


(b)Results obtained from the Micaz sensors simulation

Figure 1: Total Energy Consumption per bit versus Time Spent in the On mode/ Total Time for different distances at a packet size of 2000 bits

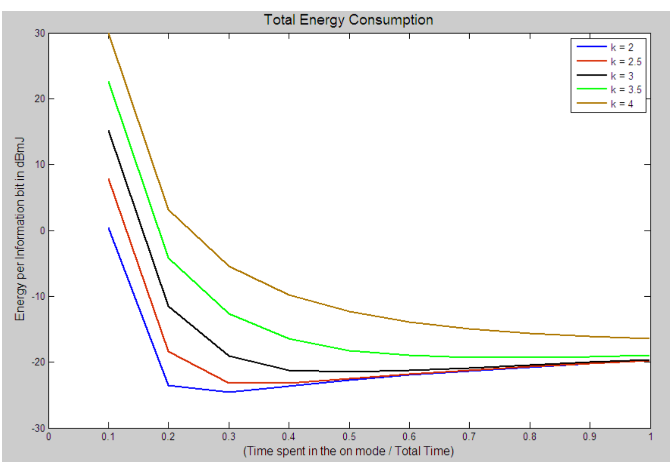


(a)Results obtained from the mathematical model

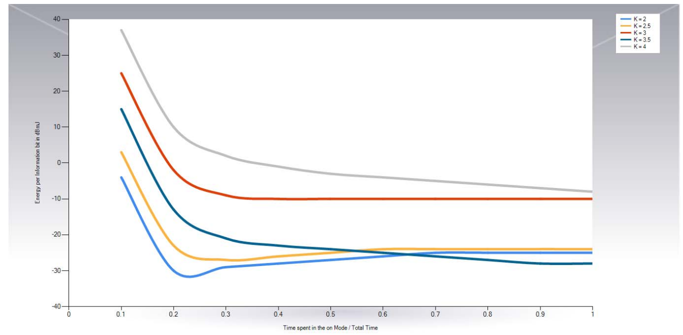


(b)Results obtained from the Micaz sensors simulation

Figure 2: Total Energy Consumption per bit versus Time Spent in the On mode/ Total Time for different packet sizes at a distance of 30 metres

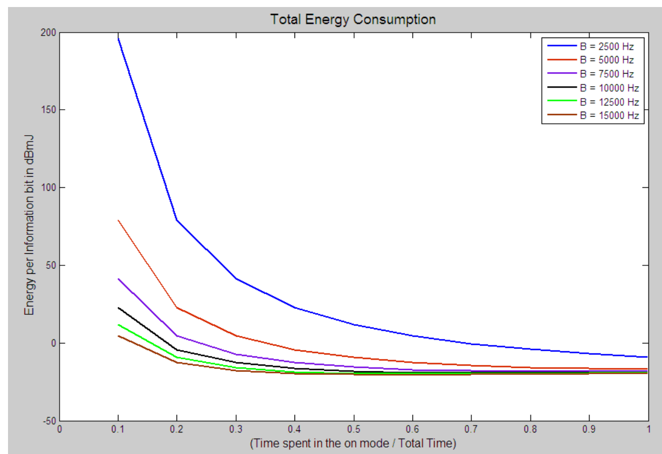


(a)Results obtained from the mathematical model

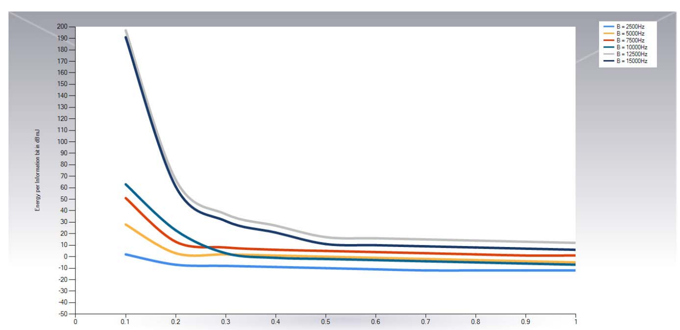


(b)Results obtained from the Micaz sensors simulation

Figure 3: Total Energy Consumption per bit versus Time Spent in the On mode/ Total Time for different path loss exponent (k) at a distance of 30 metres

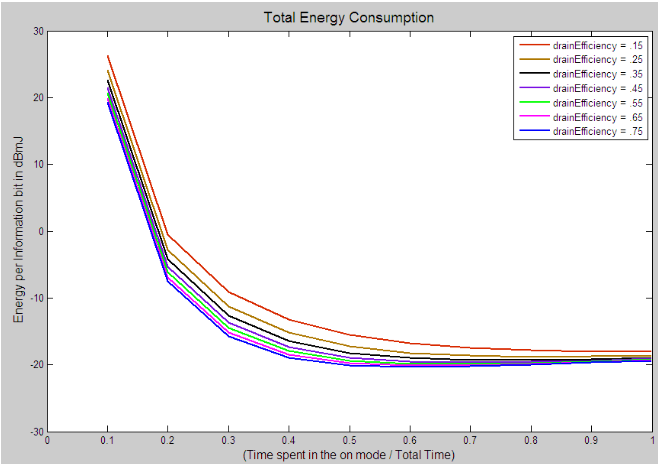


(a)Results obtained from the mathematical model

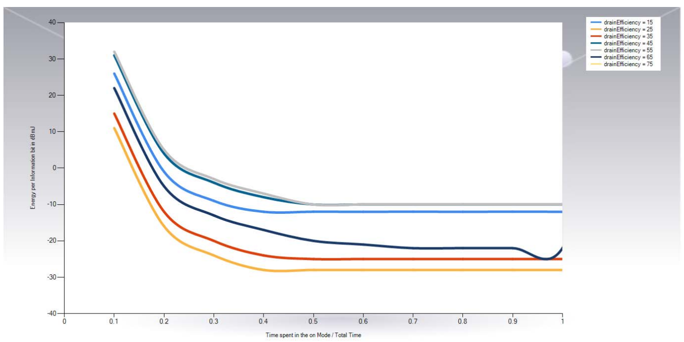


(b)Results obtained from the Micaz sensors simulation

Figure 4: Total Energy Consumption per bit versus Time Spent in the On mode/ Total Time for different bandwidth at a distance of 30 metres



(a)Results obtained from the mathematical model



(b)Results obtained from the Micaz sensors simulation

Figure 5: Total Energy Consumption per bit versus Time Spent in the On mode/ Total Time for different drain Efficiency at a distance of 30 metres

V. CONCLUSIONS

Although wireless sensors networks are very popular, their usage is restricted due to the limited power available through their life cycle. Once their power is depleted, sensors might be replaced or recharged if possible. In this paper we present a model for the power consumed in communications of the wireless sensors. The presented model for power communications takes into consideration parameters such as power consumption for the active mode, power consumption for the sleep mode, power consumption for the transient mode, transmission period, transient mode duration, sleep mode duration, and active mode duration.

In order to examine the validity of our model, we examined it versus practical scenarios using Micaz motes. We have evaluated the total energy consumption per bit versus Time Spent in the On mode/ Total Time for different parameters such as: packet size, distance between sensors, path loss, bandwidth, and drain efficiency. The practical results are accurate within 5% of the theoretical model.

The results presented in this paper show the importance of such a model from the designer perspective. The model can be used as a design tool as well as a research tool to evaluate the network performance.

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