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EXPERIMENTAL MEASUREMENTS OF THE POWER CONSUMPTION FOR HARDWARE PLATFORM eZ430-RF2480

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Abstract: **One of the most important characteristics that defines the fields of Wireless Sensor Networks is the focus on energy consumption. Understanding energy consumption is an essential factor for sensors networks operating on limited power reserves, since many sensors nodes are powered by batteries. Once the battery of a node has depleted the node fail making the network useless. This paper describes a series of experiments which obtained detailed measurements of the power consumption on eZ430-RF2480. The data is presented as a collection of equations for calculating the power consumption and battery lifetime in transmitting, receiving, and requesting data packets.**

Keywords: *sensor networks, eZ430-RF2480 platform, power consumption, periodic transmission.*

I. INTRODUCTION

Energy consumption is an important characteristic of Wireless Sensors Networks and a crucial factor to determine the lifetime of a sensor network since many sensor devices are usually powered by batteries. A deep evaluation of energy consumption is significant before deployment. Once sensor nodes are deployed and a battery of a node is depleted, it is impossible to change the battery when the node is running out of energy, making a network of small devices useless. Battery replacement is a very difficult operation, sometimes even impossible, costly, environmental unfriendly and an important factor in limiting successful large scale deployments. For this reasons, most of the deployed batteries – operated wireless sensor networks are limited to a small number of nodes, 64 nodes in [1], 100 nodes in [2].

In this paper, it is described a series of experiments which were performed measurements of the power consumption on miniaturized hardware platform eZ430-RF2480. We have looked at the average current consumption for two different scenarios: transmission of data with data acknowledgement and automatic data requests (data polling). Based on this experiments the expected lifetime of a battery operated system was estimating.

The rest of the paper is organized as follows: In Section 2 we present the related work. In Section 3 we shown the system hardware used during our experiments. In section 4 is presenting the system connectivity. The experiments are explained in Section 5, and the results and measurements evaluation are explained in Section 6. We present our conclusions in Section 7.

II. RELATED WORK

Most power measurements methods found in sensor network research were performed in the classic lab.

Ritter H. et al. [3] proposed in their paper a method for experimental lifetime measurements of sensor networks. It was designed for accelerated evaluation of the battery lifetime for sensors node programs. In this proposal they presenting a hardware methodology using special capacitors with very large capacities, called Gold-Caps that enables short-term experiments with duration no longer than a few hours. The node discharged the capacitor while executing the target program and died when the capacitor was depleted. The lifetime of the application was measured and used for predicting the lifetime with a real battery.

Another method proposed by I. Haratcherev et al. [4] is PowerBench, a scalable testbed infrastructure for benchmarking power consumption. PowerBench includes hardware components as well as software for capturing the power traces of all nodes in the testbed in parallel. PowerBench was validates to accurately measure the power consumption with a 30μA resolution at a sampling rate at 5 kHz. The software developed includes programs to run applications on the 24 nodes, to collect the resulting power traces, and to visualize them or to compute the average power consumption. The power consumption was measured by means of a shunt resistor, op-amp, and ADC.

A tested power measurement solution was proposed by L. Selavo [5], presenting a SeeMote sensor module design that provides a graphical in the field interface for wireless sensor networks. The module was fully implemented as a sensor board for MICAz motes. The module has a MMC and SD memory card interface that allows for removable storage. Also has a power meter component that sampled external power supply current and voltage, enabling the power consumption monitoring for an external device.

III. SYSTEM OVERVIEW

eZ430-RF2480 is a miniaturized hardware platform demonstrating ZigBee embedded networking and low power consumption for a node with an MSP430F2274 and a CC2480 (ZigBee Network coprocessor). The system on the platform eZ430-RF2480 consists of two batteries, an eZ430 USB Emulator Board, an eZ430 Battery Board, and two

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CC2480 Target Boards [6], all shown in Figure 1.


a) b) c)

Figure 1. The system on the hardware platform eZ430-RF2480 a) eZ430 USB Emulator Board, b) eZ430 Battery Board, c) CC2480 Target Board

i) The *eZ430 USB Emulator Board* provides a USB to serial connection and power supply for the CC2480 Target Board.
ii) The *eZ430 Battery Board* interfaces to the CC2480 Target Board to provide power for use in mobile situations.
iii) The *CC2480 Target Board* demonstrates Z-Accel by connecting a MSP430F2274 to the CC2480 Network Processor over SPI (Serial Peripheral Interface). This board is a reference design for CC2480 and demonstrates the use of Z-Accel designed to minimize the board size using a chip antenna. The target board includes two LEDs, one Red and one Green, a push button, and five GPIO (General Purpose IO) lines exposed for expanding the I/O (Input Output) interface.

The CC2480 Target Board can either be connected to the USB emulator creating *eZ430-RF2480 Dongle* which will act as the ZigBee network Coordinator and a gateway for communication with a computer, shown in Figure 2, or it can be connected to the supplied battery board creating *eZ430-RF2480 Battery Node* which will act as an End Device, shown in Figure 3.


Figure 2. eZ430-RF2480 Dongle


Figure 3. eZ430-RF2480 Battery Node

iv) The *battery type* has a direct impact on the lifetime of the systems. Typical, low cost batteries are AA and AAA Alkaline. The average capacity of one AA battery is 2500mAh and 1200mAh for one AAA battery and determines for how many hours the battery will be able to supply a specific current. There are many other criteria than the capacity that should be carefully considered before selecting a battery type like voltage, peak current, rechargeable, material, size, and environmentally friendly. Two NiMH 1000mAh rechargeable batteries are used in our system.

IV. CONNECTIVITY

The system implemented for measuring the power consumption on eZ430-RF2480 consists of a thermocouple allowing temperature and on-board voltage level measurements and passing data through eZ430-RF2480 Battery Node.

The system is designed to sense the temperature and on-board voltage level and send periodically the data via ZigBee network to eZ430-RF2480 Dongle which is connected to a computer through USB port. The communication between Battery Node device and Dongle device are carried out via ZigBee network.

ZigBee is a wireless technology developed as an open global standard to address the unique needs of low cost - allowing the technology to be widely deployed in wireless control and monitoring applications, low power – usage allowing a longer life with smaller batteries, and a wireless mesh networking standard - providing high reliability and more extensive range [7].

The ZigBee standard operates on the IEEE 802.15.4 physical radio specification. The 802.15.4 specification is a packet based radio protocol intended for low-cost, battery-operated devices. The protocol allows devices to communicate in a variety of networks topologies and provides the ability to run for years on inexpensive batteries for a host of monitoring and control applications.

There are three logical device types in a ZigBee network: (1) Coordinator, (2) Router and (3) End Device [8]. A ZigBee network consists of a single Coordinator node, multiple Router and End Devices nodes. The *Coordinator* is the first device on the network starting the ZigBee network. The Coordinator node chooses a channel and a network identifier and then starts the network. A *Router* performs networking functions for (1) allowing other device to join the network (2) multi-hop routing (3) assisting in communication for its child battery-powered end devices. An *End Device* has no specific responsibility for maintaining the network infrastructures, so it can sleep and wake up as it chooses. Therefore, End Device can be powered by batteries for long period of time.

For all the measurements that are done on the eZ430-RF2480 platform, the ZigBee network consists only of two logical devices: a single Coordinator node and one End Device node.

The MSP430 runs the ZigBee Accelerator Sample Application that implements a manufacturer specific ZigBee application profile with two ends points: Sink which is mapped to the logical device type Coordinator and Source which is mapped to the logical device type End Device [9]. The system was designed in that way all the experiments were performed with only one Sink and one Source in the ZigBee network. The Sink receives temperature and voltage samples sent periodically from the Sources. In between the data transmission the End Device goes to sleep to save power.

V. EXPERIMENTS SET-UP

The method used to measure the power consumption on hardware platform eZ30-RF2480 assumed:
(i) Carrying out experiments with one Sink and one Source in the ZigBee network.
The system consists of an eZ430-RF2480 Battery Node connected to the thermocouple, an eZ430-RF2480 Dongle connected to a computer through USB port. The system was designed to sense the temperature and on-board voltage level, passing them through Battery Node (Source), and to send periodically the data via ZigBee network to Dongle (Sink).
(ii) Transmitting the data with acknowledgement at different frequencies.
Application Acknowledgement (APS ACK) is the reply from the receiver of an application layer packet, saying that the packet was received by the recipient with no errors [9]. Using APS ACK is the only way a ZigBee node can make sure that the packet it sent was received by the intended recipient.

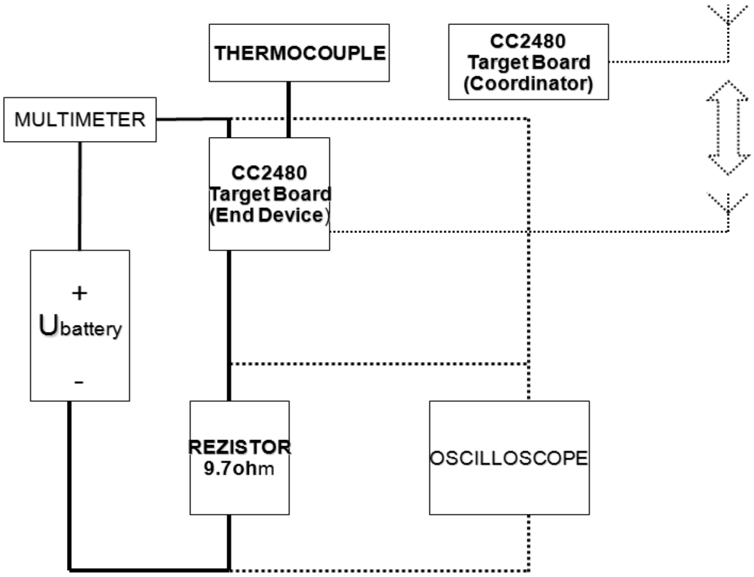

Figure 4. Measurement setup

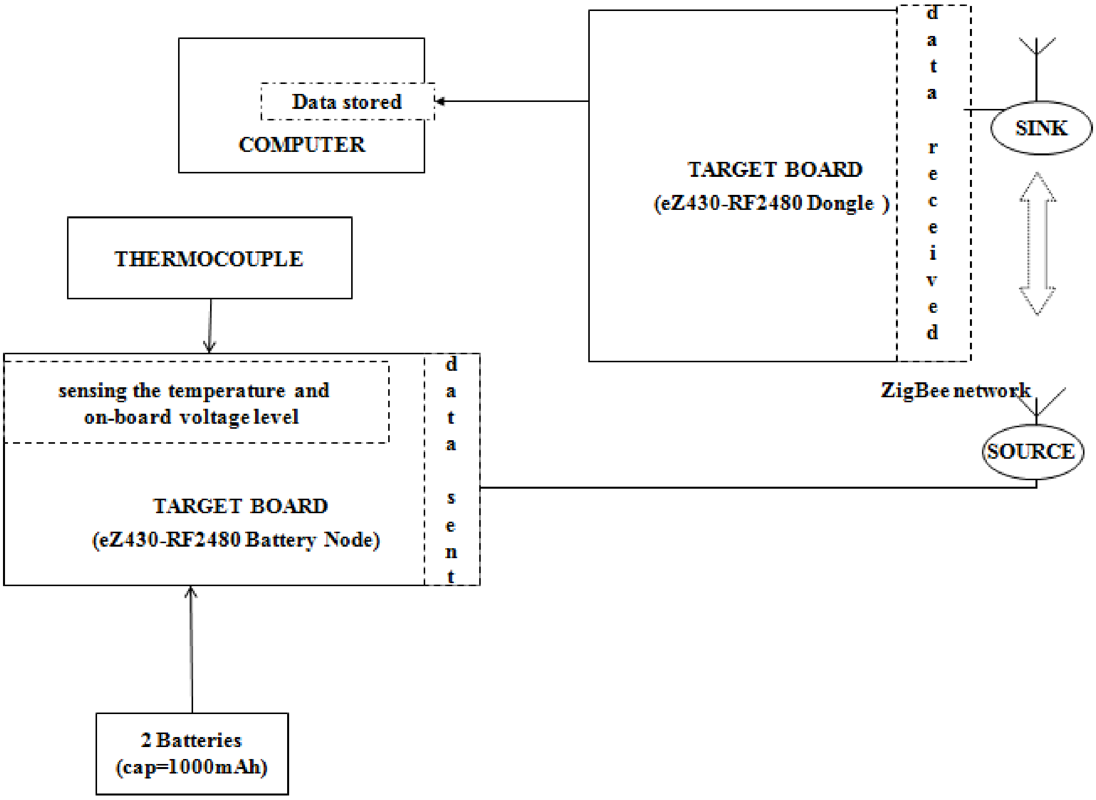

Figure 5. System configuration

The End Device requests the acknowledgement packet from the receiver after having transmitted the packet. After receiving the acknowledgement, the End Device will send a last data request to check whether additional packets are on its way to the node. The End Device will enter deep sleep if no packets are received.

(iii) Transmitting the data with *data polling*.

The only way an end device will be able to receive data from another node is to periodically send data requests to the associated device. If there are packets destined for the End

Device, the packet can be sent once the End Device asks for them.

(iv) Visualizing the current profile on an oscilloscope by measuring the difference between the voltage drop over the batteries and voltage drop over a fixed resistor. Also a multi meter was used to measure the current during sleep mode. The set-up is illustrated in Figure 4.

The oscilloscope provides a graphical representation on the voltage difference. Since is a linear relationship between the voltage and current, the same graphical representation illustrates the current consumed by the system.

(v) Evaluating the current consumed by the system, power consumption, and battery life.

The calculation of the current is based on the well known relation:

$$U = R * I \tag{1}$$

where U is the voltage, R is the resistance and I is the current. The R should not be too large, since it will reduce the effective voltage over the target board itself.

$$U_{target\_board} = U_{battery} - R * I \tag{2}$$

To keep the measurement system simple, the error introduced by the resistor was accepted.

Once the current was determined, the overall average current consumption was calculating using the formula below [9]:

$$I_{average} = (D/P) * I + (1 - (D/P)) * I_{sleep} \tag{3}$$

where D is the duration based on averaging values from measurements, P is the period of transmission, I is the average current consumption, and I_{sleep} is the current consumption when the system is in sleep mode.

The total lifetime of the system was calculated using the following formula:

$$Capacity_{battery} / I_{average} = Lifetime \tag{4}$$

VI. EXPERIMENTAL RESULTS

The system configuration for measuring the power consumption on hardware platform eZ430-RF2480 is shown in Figure 5.

Using the oscilloscope, two pictures of the dynamic power consumption of the system during transmission of one of the packets was taken. In figure 6 is showing the transmission of data with Application Acknowledgement (1 packet sent every 2 seconds) with data polling disabled. In figure 7 is showing the transmission of data with APS ACK (1 packet sent every 4 seconds) with data polling activated, the system being configured to send data requests to the associated device every one second.

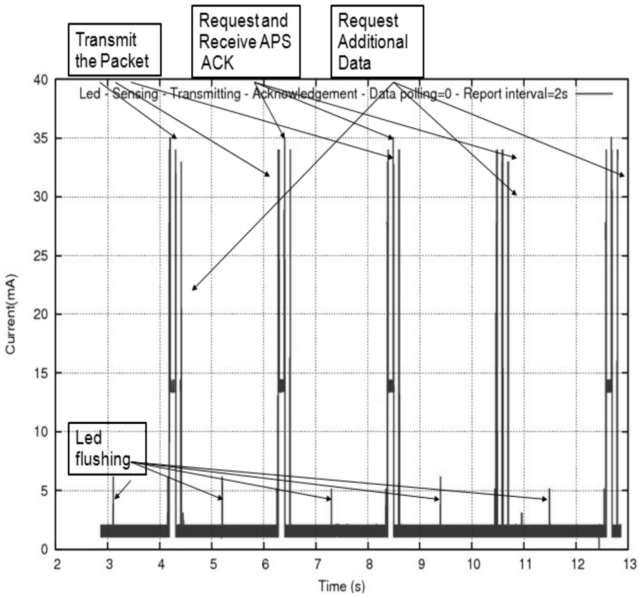

Figure 6. Transmission of data with APS ACK

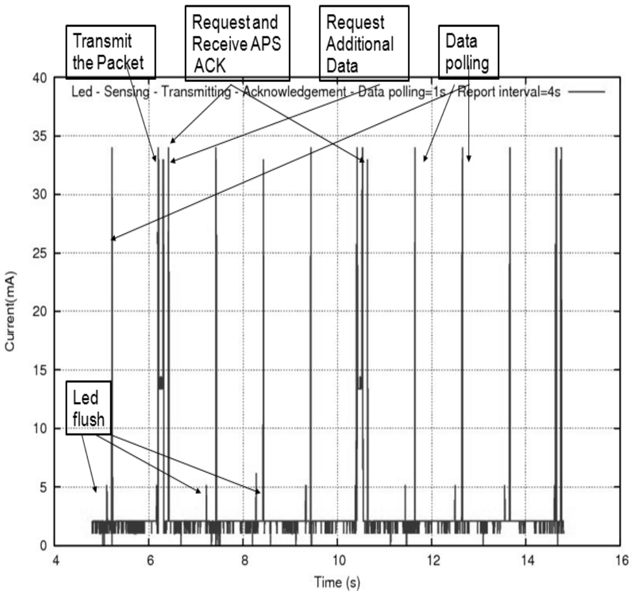

Figure 7. Transmission of data with APS ACK and data polling

Based on the graphs above, the average current consumption for the active period was calculated. Following the steps from [9], the sequence in different phases was divided and the approximate current and duration for each phase was measured.

The results for transmission of data with Application Acknowledgement are shown in table 1. In table 2 are shown the results of periodic data request (data polling).

Table 1.Measured current consumption during transmission with APS ACK

Id	**Description**	**Duration [ms]**	**Voltage [mV]**	**Current [mA]**	**[ms*mA]**
1	Acquire sample	40	12	1.23	49.2
2	Startup	10.37	114	11.75	121.84
3	Transmit packet	2.81	306.6	31.60	88.85
4	Wait before requesting APS ACK	100	120	12.37	1237
5	Request and receive APS ACK	6.43	303	31.23	200.80
6	Post processing of packet	4.72	116	11.95	56.40
7	Enter Low Power Mode 2	100	0.0097	0.001	0.10
8	Request data	7.2	186.4	19.21	138.31
	Sum	271.53			1892.5
	Average			**6.96**	

Table 2.Measured current consumption during data polling

Id	**Description**	**Duration [ms]**	**Voltage [mV]**	**Current [mA]**	**[ms*mA]**
1	Wake up	2.12	114	11.75	24.91
2	Transmission of data request and receive ACK	3.8	304	31.3	118.94
3	Prepare for sleep	1.280	112	11.54	14.77
	Sum	7.2			158.62
	Average			**22.03**	

For computing the total average current consumption for the system during transmission of data with APS ACK, the current consumption when the system was in deep sleep mode was measured using an ampere meter and the value obtained was 660nA. For automatic data requests, the value for the current consumption during sleeping mode was 959nA. It can be observed that the sleep current will be different depending if data polling is enabled or not.
Substituting in the formula (3), we get:

$$I_{average} = (271.53/P) * 6.96\text{mA} + \\ + (1 - (271.53/P)) * 0.00066\text{mA} \tag{5}$$

$$I_{average} = (7.2/P) * 22.03\text{mA} + \\ + (1 - (7.2/P)) * 0.00096\text{mA} \tag{6}$$

The period of transmission depends how the systems is configured to transmit the data. The calculation from formula (6) does not take into account the scenario where the polling device actually receives a packet.
For a transmission of data every 4 seconds with APS ACK and data polling every one second, we get:

$$\begin{aligned} I_{average} &= (1/4)(271.53/4000) * 6.96\text{mA} + \\ &+ (3/4)(7.2/1000) * 22.03\text{mA} + \\ &+ [1 - (1/4) * (271.53/4000) - \\ &- (3/4) * (7.2/1000) * 0.00096\text{mA}] * 0.00066\text{mA} \end{aligned}$$

As a final step, the total lifetime of the system was calculated with the formula (4).

The results for the overall average current consumption and total lifetime of the system are shown in table 3 and it can observe the difference between two systems: when the End Device is configured to transmit one packet every 10 seconds with APS ACK the board can operate for 220 days with AAA batteries with 1000mAh capacity, but if the End Device is configured to transmit with data polling the board operated for more days, 2477, with the same batteries. By using other types of batteries, like AA batteries with 2500mAh capacity, the board can operate for 551 days with APS ACK.

Table 3.The total lifetime of the system

Period of transmission [ms]	**APS ACK**		**Data polling**	
	Average current [mA]	Battery life [days]	Average current [mA]	Battery life [days]
1000	1.890	22	0.159	261
2000	0.945	44	0.080	519
3000	0.630	66	0.053	774
4000	0.472	88	0.040	1025
5000	0.378	110	0.032	1274
6000	0.315	132	0.027	1521
7000	0.270	154	0.024	1780
8000	0.236	176	0.020	2005
9000	0.210	198	0.018	2242
10000	0.189	220	0.016	2477

In Figure 8 is shown the difference between two systems, where one is using data acknowledgement with 1000mAh battery capacity, whereas the other used APS ACK with 2500mAh battery capacity. By combining these two types of batteries transmitting one packet every nth second, the lifetime between the two graphs can be achieved.

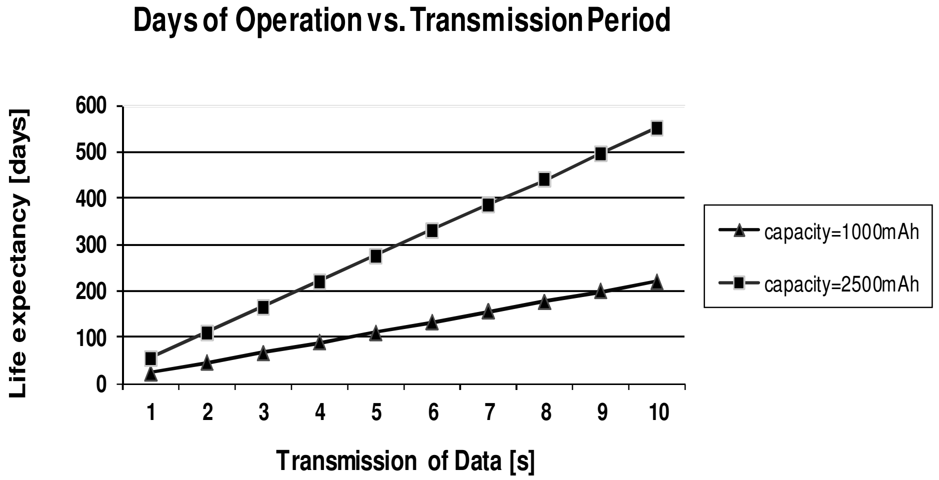

Figure 8. Lifetime of the system

VII. CONCLUSIONS

Energy consumption has become a major concern in computer system design over the past years and a crucial characteristic for determining the life of sensor networks since many sensor devices are battery powered. Once sensor nodes are deployed, it is impossible to change batteries when nodes run out of energy, making a network of small devices useless. Therefore a deep evaluation of accurate energy analysis and precise lifetime prediction is necessary.

In this paper we have gone through the basics of performing current consumption measurements and estimating the expected lifetime of a battery operated system. Then we looked more closely at the miniaturized hardware platform eZ430-RF2480 and performed a series of measurements on the CC2480 Target Board for determining the lifetime of the system depending of various configuration options in the software.

A factor that influences the power consumption strongly is the transmission period. Increasing the transmission period can be done by making sure the data is only sent when it must and then send as much data is possible. It is better to transmit one packet with two samples rather than to transmit two packets with one sample each. In alarms and security systems it is important that all transmitted packets to be received by the recipient; in non-critical systems, losing a packet is not so crucial.

Understanding the lifetime contributions and combining the various elements, we can take a good estimate of battery lifetime of the system design.

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