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Original citation & hyperlink:

Poole, N. , Mo, T. and Brusey, J. (2009). Power consumption of microelectronic equipment for wireless sensor networks In Nanotechnology 2009: Fabrication, Particles, Characterization, MEMS, Electronics and Photonics (pp.534-537). NSTI.
http://www.nsti.org/procs/Nanotech2009v1/6/M72.404

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Power Consumption of Microelectronic Equipment for Wireless Sensor Networks

N. R. Poole*, Y. K. Mo*, J. Brusey*, M. Langley** and R. Hazelden***

*Cogent Computing Applied Research Centre, Coventry University CV1 5FB
**Vibro Meter UK, Viables Industrial Estate, Basingstoke, Hampshire, RG22 4BS
***TRW Conekt, Stratford Road, Solihull, B90 4GW

ABSTRACT

Previous work has reported on typical power consumption data for wireless sensor networks employing micro-electronics such as the Mica2 mote. This work is extended in this paper to cover power consumption in typical operational deployments of three battery powered wireless sensor network systems. Data for a Linux system based on XScale PXA270 processors, Texas Instruments eZ430 demonstrators and Arch Rock IPsensor nodes are presented. The effects of wireless communication, software functionality and processor configuration are illustrated. Conclusions are that power consumption and battery life are strongly influenced by processor capability. Minimizing wireless communications is always important while the effect of processor throttling is more complex and requires further research.

Keywords: power consumption, wireless sensor networks, power efficiency, power saving, battery sizing

1 INTRODUCTION

Various authors' have reported on power consumption for a variety of microelectronic devices deployed in wireless sensor applications. Davis and Miller [1] provide data for Mica2 motes based on the Atmel ATMega 128 processor with a CC1000 radio running TinyOS. Their results clearly show the significance of subsystem activity on power consumption. Raghunathan et al. [2] also consider the power consumption of Mica2 technology in the context of the solar powered Heliomote. The focus of their work is on the optimization of the solar energy harvesting system. Solar power is also the main focus of the work by Jeong et al. [3] which considers Heliomote and Trio wireless sensor nodes. The Fleck1, an integrated, solar powered wireless sensor node, also based on the Atmel ATMega 128 processor but with a Nordic nRF903 radio, is reported by Corke et al. [4]. More general coverage of energy harvesting techniques and power consumption for wireless sensor networks is covered in [5,6,7]. Wines and Braathen [8] authored a technical report considering the power consumption of the eZ430-RF2480 demonstration platform and describe companion measurement techniques. Their work is particularly valuable in demonstrating the influence of radio activity on power consumption and in predicting life expectancy under battery power.

The main additional value of the current work is in providing power consumption data for higher performance wireless sensor processors running Linux in typical applications. It also provides useful data for TelosB compatible nodes and reinforces earlier findings on MSP430 systems using CC2480 radios.

2 APPLICATIONS AND METHODOLOGY

The authors' research group has been involved with investigations into wireless sensor networks over a number of years. This work has been wide ranging [9] involving the following typical applications:

- Wearable sensor applications with a particular emphasis on explosive ordinance disposal suits (EOD).
- Industrial process monitoring [10] involving temperature, vibration and sound sensing.
- Building monitoring for commercial and residential scale premises, typically monitoring temperature, humidity, illumination CO_2 level and presence.
- Posture monitoring using wearable body accelerometers connected via a wireless network.
- Solar powered 802.11g wireless router nodes.

Specific topics researched have included: signal processing, data visualization, field mapping, data storage and transmission protocols, fault detection and management, test and debugging, and software engineering techniques for wireless sensor networks. Wherever possible practical demonstrators have been implemented to prove the technology and gain insight to real-world deployment issues. The majority of systems have been battery powered with power consumption and associated battery lifetime critical issues. It has been necessary to evaluate power consumption during the course of this work for a range of devices as described below and this work has grown to become a research theme in its own right.

3 DEVICES EVALUATED

The work provided power consumption data on three distinct microelectronic systems (figure 1) offering varied processing and interface capabilities.

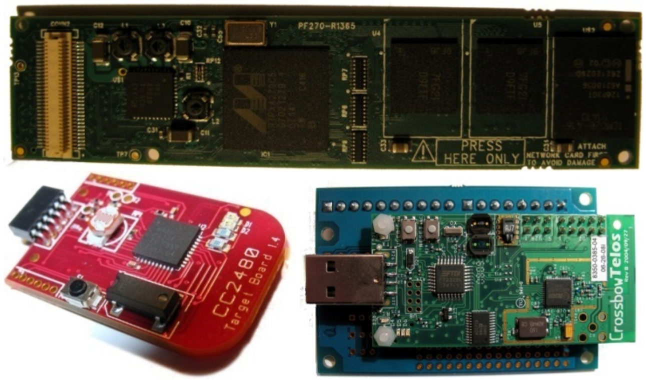

Figure 1: Gumstix, eZ430, and ArchRock platforms.

3.1 Marvell XScale Processor

The Marvell XScale processor has been deployed employing the Gumstix Verdex [11] range of modules. The versions with which most experience has been gained use the 32-bit PXA270 processor operating at clock speeds of 200 – 400 MHz. They provide 64 MB RAM, 16 MB flash storage and Infineon PBA31308 based class 2 Bluetooth communications. These systems have been deployed in a variety of applications with software developed using the Linux OpenEmbedded build environment provided by the manufacturer. For wireless sensor networks the Gumstix are connected to a proprietary interface board that provides power management, a UCB1400 audio codec, USB, I^2C and optionally Zigbee communications via a Maxstream XBee module. The composite system has a 100 x 30 mm footprint and operates at a nominal power level around 1W. Normal deployment power was from 3-off 800mAh AAA NiMH cells or an 1800 mAh Li-ion battery.

3.2 Texas Instruments eZ430-RF2480

The second microelectronic system evaluated was the eZ430-RF2480 demonstrator system from Texas Instruments [12]. This employs the ultra low power MSP430F2274 16-bit processor with 32 kB + 256 B flash and 1 kB RAM. Communications are provided by the CC2480 with an IEEE802.15.4 radio along with an onboard Texas Instruments Z-stack running on a dedicated processor giving Zigbee compatibility. This approach allows the application processing to take place on a relatively small and simple device with the user isolated from the complexities of low-level communications protocols. Software development takes place on industry standard integrated development environments for the MSP430 series such as Texas Instruments Code Composer or IAR Embedded Workbench. The device has been predominantly deployed in industrial monitoring applications to date. Deployment power source was 2-off 800 mAh NiMH cells.

3.3 Arch Rock IP Sensor Node

The final microelectronic device considered has been deployed primarily for building monitoring applications. It is the Arch Rock IPsensor node [13] which is based on Berkeley TelosB [14] compatible electronics. It again employs a Texas Instruments MSP430 series processor, although higher specified with 48 kB flash memory, 10 kB RAM and 128 kB external flash. Communications are also via an IEEE 802.15.4 radio although this time running LoWPAN for triply redundant mesh networking. Standard on-board sensors include temperature, humidity and illumination. To date the devices have been deployed with the standard Arch Rock software which has the flexibility to allow a variety of external sensors to be connected over the standard interfaces provided. A software development kit is available if custom software is necessary for turnkey applications. Deployment power source was 2-off 1800 mAh AA NiMH cells.

4 RESULTS

4.1 XScale Gumstix Platform

Data was obtained from an industrial monitoring application employing a processor module, proprietary interface board and variable number of temperature sensors connected over the I^2C bus. Nominal power consumption results for different processor configurations [15] and system elements are given in table 1. An important practical observation was that the system will take up to 78% additional power during its bootup sequence. This is due to the fact that the PXA270 will initialise in its maximum configuration by default and when the operating system takes control it can switch off any peripherals that are not required, such as the LCD interface in this case.

Feature / Mode	Power consumption (mW)
PXA270 max config	1012
PXA270 fast mode	552
PXA270 idle mode	276
PXA270 deep idle	184
PXA270 sleep mode	92
Verdex module (fast mode)	631
Bluetooth module (inactive)	302
XBee Zigbee module	225
Serial interface module	147
Interface board	78
Temperature Sensor (each)	1.65
Total system (typical)	1125

Table 1: Gumstix platform nominal power consumption.

Further investigations were directed at determining how power consumption varied with a variety of software processing on the node and the amount of radio communication employed. Table 2 illustrates that as the functionality expected from the node software increased there was a corresponding increase in power consumption.

It was noteworthy that wireless communications is an expensive resource in terms of power consumption. Using Bluetooth a 46% increase in power was observed when transmitting all node sensor data back to a base station at 4 Hz relative to processing and storing data locally. The transmission of data was more power hungry than reception. Reducing the sample rate naturally resulted in reduced power necessary for communications.

System configuration	Power consumption (mW)
Idle mode	585
Software sensor filter	718
Bluetooth communications	800
Filter and Bluetooth comms	929

Table 2: Gumstix power variation with configuration.

Figure 2 illustrates the power trend during the Gumstix platform boot and operation sequence. Significant observations include: additional power was consumed during boot-up and when comptational load was placed on the processor by running application processes. Making extensive use of radio communications also significantly enhanced the power consumption. Typical battery life for the Gumstix system in operational deployment was in the range 10 to 17 hours when running off AAA cells, dependent on software configuration.

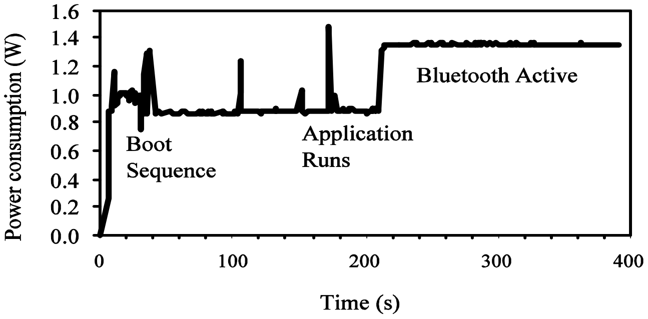

Figure 2: Typical Gumstix platform power trend.

4.2 eZ480-RF2480

Typical power consumption levels for the eZ430-RF2480 system are shown in table 3. The precise level was subject to some variation depending on the work that the MSP430 application processor and CC2480 Zigbee radio component are performing at any specific time. The power trend characteristic in figure 3 illustrates the typical variability that was observed. The main observations are that the CC2480 Zigbee processor consumes by far the greatest proportion of power in the system. The minimum power consumption level from an active CC2480 was at least 15 times that for the maximum observed power from the MSP430 and when radio communication was taking place this can rise to 38 times. The power management strategy in such systems is normally to switch the radio into an inactive state whenever possible and minimize the period over which data is transmitted. Typically battery life of the eZ430-RF2480 system operating from AAA cells in a monitoring application at a 1 Hz sample transmission rate is calculated to be of the order of 1 year.

Feature / Mode	Power consumption (mW)
MSP430 Low power mode	0.002
MSP430 Active	4 to 18
Per active LED	7.5
CC2480 powered	36
CC2480 TX|RX	91.5
Maximum observed	112

Table 3: eZ430 nominal power consumption.

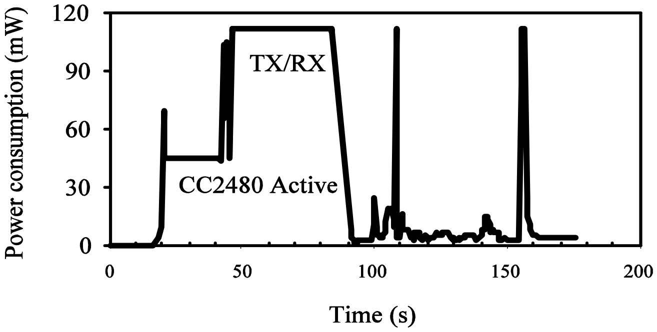

Figure 3: Typical eZ430 platform power trend.

4.3 Arch Rock IPsensor Node

Power consumption values were evaluated for the Arch Rock IPsensor Node components during a typical building monitoring scenario. This involved the deployment of 10 sensor nodes within and outside a residential property. The nodes were configured to transmit environmental data back to a central Arch Rock PhyNet router and server combination at regular intervals.

Feature / Mode	Power consumption (mW)
Inactive mode	0.54
Active LED	15
Regular pulse	63
Radio active	50 - 70
Maximum observed	85

Table 4: Arch Rock (TelosB) nominal power consumption.

Summary results are shown in table 4. The data was acquired when operating on a 300 s sampling period and employing an external CO_2 sensor interface that required to be powered (from its own supply) for 10 s per measurement. Data was transmitted from sensor nodes back to the router employing the LoWPAN IEEE802.15.4 protocol. Variation of power consumption over the boot-up, association and power save cycle is shown in figure 4. As with the eZ430 system expected battery life is primarily determined by the proportion of time for which radio communications are active.

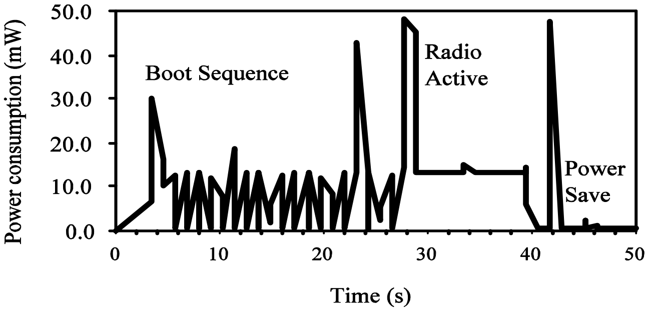

Figure 4: Typical Arch Rock platform power trend.

5 CONCLUSIONS

Processor performance level is a key determinant of power consumption for wireless sensor nodes. While it is attractive to work in a software environment offering the capability and resources of the Linux operating system this requires a power level at least 10 times greater than a low-power micro-processor. In turn, for applications requiring battery power this will typically result in lifetimes measured in days rather than months, restricting potential usage scenarios.

Wireless communication is a relatively expensive resource in terms of the power consumption required to achieve data transfer. In addition to the transmitted power-levels the micro-electronic resources required to enable the use of protocols like Zigbee and Bluetooth can be significant. To achieve good power utilization it is important to structure applications to minimize the amount of radio transmission and place wireless resources in low-power / sleep modes when not in use.

There are two important trade-offs to consider when determining the hardware and software configuration on wireless sensor nodes. First, it is important to consider processor speed. While throttling the processor clock will save instantaneous power it will result in the processor being active for longer and a shorter period spent in low-power modes so not necessarily provide any practical benefit. Secondly it is necessary to address the software functionality that must run on the node in comparison to the processor capability required and amount of wireless communication required. Being able to employ small low-power micro-electronic devices will enable significant power savings and extended battery lifetimes. The position on software processing and radio communication is more complex and requires detailed analysis for each application. This is to be the subject of further research.

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