On Modeling Networks of Wireless Microsensors

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1. INTRODUCTION

Recent advances in low-power embedded processors, radios, and micro-mechanical systems (MEMs) have made possible the development of networks of wirelessly interconnected sensors. With their focus on applications requiring tight coupling with the physical world, as opposed to the personal communication focus of conventional wireless networks, these wireless sensor networks pose significantly different design, implementation, and deployment challenges. Their application-specific nature, severe resource limitations, long network life requirements, and the presence of sensors lead to interesting interplay between sensing, communications, power consumption, and topology that designers need to consider. Existing tools for modeling wireless networks focus only on the communications problem, and do no support modeling the power and sensing aspects that are essential to wireless sensor network design. In this paper, we present a set of models and techniques that are embodied in a simulation tool [1] for modeling wireless sensor networks. Our models are derived with detailed power measurements involving 2 different types of sensor nodes representing two extremes; high-end WINS nodes [2] by Rockwell and low-end experimental nodes that we have built. The WINS nodes have a StrongARM S1100 processor and a 100m-range radio and can carry a wide variety of sensors. The experimental nodes feature an AVR 90LS8535 microcontroller from Atmel and a low power radio 20m-range from RFM Monolithics and a similar to the COTS nodes from UC Berkeley [3].

To instrument sensor network scenarios in a simulation environment, more features need are also introduced. The notion of a sensing channel is used to propagate stimuli to the sensors. Target models are responsible for generating the stimuli that trigger the sensors, which in turn become communication traffic towards a central base station. All these actions affect power consumption, which directly affect the useful lifetime of the network. Since power consumption is a crucial factor we focus our study on empirical measurements of power consumption on sensor nodes that can be use to produce accurate models in a simulation environment. The sections that follow provide a brief overview of the sensor node and battery models and present the results of our power measurements.

2. SENSOR NETWORK AND NODE MODELS

A sensor network is modeled as a set of heterogeneous entities. Sensor nodes deployed over the area of interest are triggered by a certain set of stimuli that eventually result in a sensor report that is transmitted to a remote base station. Following this paradigm in a simulation environment, three main types of sensor nodes need to be created supported: 1) **target nodes** that stimulate the sensors, 2) **sensor nodes** to monitor events and 3) **user nodes** that query the sensors and are the final destination of the target reports.

The most interesting model is that of the sensor node. In addition to the communication protocol stack, this node model also includes a sensing stack that provides the interface to the sensor physical layer. The two stacks are connected together with an application layer, and together they constitute the algorithmic component of the node. To model power consumption, power models of the individual components are provided together with a battery model. As the protocols execute on the hardware, a corresponding amount of energy is depleted from the battery. Figure 1 provides an overview of the node model. This provides a flexible parametrizable model that can be applied to different sensor node architectures. The challenge in achieving an accurate sensor node model is to understand how the node consumes power.

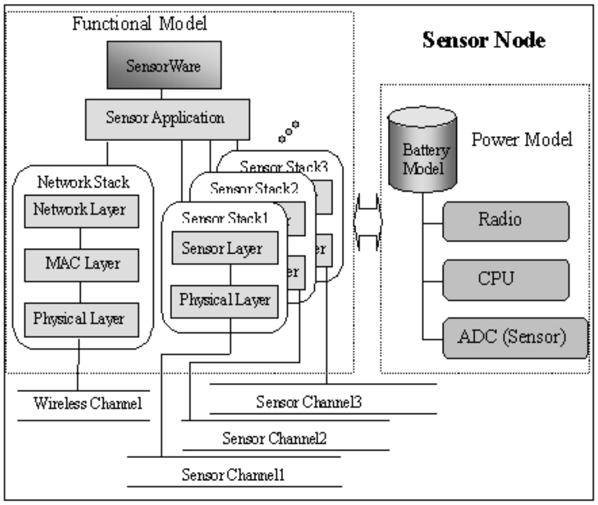

Figure 1 Sensor Node Model

3. BATTERY MODELS

3.1 Linear Battery Model

In this model, the battery is treated as linear bucket of energy. The maximum capacity of the battery is achieved regardless of what the discharge rate is. Such a model allows the user to examine the efficiency of applications by providing a simple metric of energy consumption. The remaining capacity after

Table 1 CPU Measurements for WINS and Experimental Nodes

CPU	Sensor	WINS		Experimental Node	
		Current	Power	Current	Power
Active	On	42.23mA	380mW	2.9mA	8.7mW
Sleep	On	7.0mA	64mW	1.9mA	5.9mW
Off	On	2.6mA	23.8mW	N/A	N/A
Power Down	Power Down	100µA	0.9mW	1µA	3µW

Table 2 WINS Radio Measurements

Radio Mode	Tx Power (mW)	Current Drawn (mA)	Power Consumed (mW)
Tx	0.12	43.64	395.99
Tx	0.16	43.68	396.35
Tx	0.23	43.82	397.61
Tx	0.30	43.95	398.77
Tx	0.44	44.14	400.48
Tx	0.95	45.5	412.68
Tx	1.32	45.95	416.72
Tx	1.78	45.86	424.87
Tx	2.51	47.77	433.03
Tx	3.47	48.68	441.18
Tx	10.00	59.59	538.63
Tx	13.80	63.23	571.02
Tx	19.05	68.23	615.43
Tx	27.54	73.68	663.70
Tx	36.31	79.14	711.94
Rx		41.41	375.96
Idle		38.68	351.4

Table 3 RFM Radio Measurements

Mode	Power Level	OOK Modulation				ASK Modulation			
		2.4Kbps		19.2Kbps		2.4Kbps		19.2Kbps	
	mW	mA	mW	mA	mW	mA	mW	mA	mW
Tx	0.7368	4.95	14.88	5.22	15.67	5.63	16.85	5.95	17.76
Tx	0.5506	4.63	13.96	4.86	14.62	5.27	15.80	5.63	16.85
Tx	0.3972	4.22	12.76	4.49	13.56	4.90	14.75	5.18	15.54
Tx	0.3307	4.04	12.23	4.36	13.16	4.77	14.35	5.04	15.15
Tx	0.2396	3.77	11.43	4.04	12.23	4.45	13.43	4.77	14.35
Tx	0.0979	3.13	9.54	3.40	10.35	3.81	11.56	4.08	12.36
Rx	-	4.13	12.50	4.13	12.50	4.13	12.50	4.13	12.50
Idle	-	4.08	12.36	4.08	12.36	4.08	12.36	4.08	12.36
Sleep	-	0.005	0.016	0.005	0.016	0.005	0.016	0.005	0.016

operation duration of time t_d can be expressed by following equation. Remaining capacity (in Amp*Hour) = $U = U' - \int_{t=t_0}^{t_0+t_d} I(t)\,dt$, where U' is the previous capacity and $I(t)$ is the instantaneous current drawn from the sensor node at time t.

3.2 Discharge Rate Dependent Model

The maximum battery capacity is very much dependent on the discharge rate or the rate at which the current is withdrawn from the battery. At high discharge rates, the battery capacity is significantly reduced. To consider this effect of discharge rate dependency, we introduce factor k which is the battery capacity efficiency factor that is determined by the discharge rate. The definition of k is, $k = \frac{C_{eff}}{C_{tot}}$, where C_{eff} is the effective battery capacity and C_{tot} is the total rated capacity of the battery with both terms expressed in unit of Ampere*hour(Ah).

3.3 Relaxation Model

Real-life batteries exhibit a general phenomenon called "relaxation". The relaxation occurs when the discharge current from the battery is cutoff or reduced after draining the battery at high discharge rate. As the discharge rate of the battery drops, the battery's cell voltage recovers, and the battery has a chance to recover the capacity lost due to the high discharge rate. The relaxation phenomenon is adapted to our battery model to simulate the behavior of real life battery.

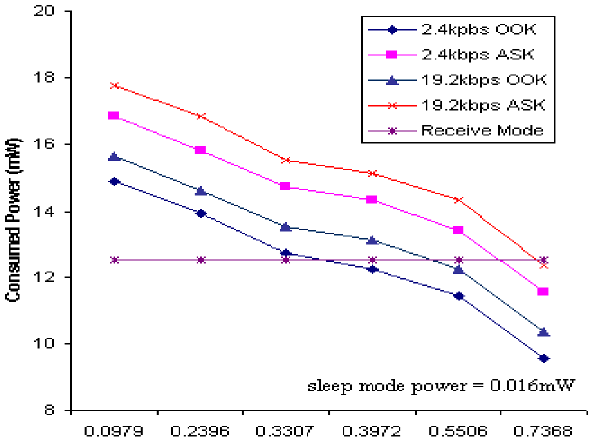

Figure 2 RFM Radio Power Comparisons

4. POWER CHARACTERIZATION

Sensor node power consumption depends on the node's mode of operation (receive, transmit, sleep, power down). During its lifetime, a node may switch between different operational modes according to a specific task or power management scheme. By measuring the power consumption at the different operational modes accurate models can be constructed and useful insight can be obtained about the individual components of the sensor nodes.

Using an HP 1660 oscilloscope and a high precision resistor we measured the power consumption of the radio and CPU of 2 types of nodes (WINS and Experimental nodes) at different operational modes. Table 1 shows the power measurements for the CPUs on the 2 nodes. The power consumption for the WINS radio is shown in table 2. The power consumption for the RFM radio is shown in table 2 and figure 2.

These measurements show some notable trends of how power consumption is distributed in a sensor node. In both nodes, the radio consumes the most power; 50-67% of the total power consumption. Furthermore, the difference in power consumption between transmission and reception in low power radios is very small. For the WINS radio the transmission power is at most 2 times greater than reception and 1.4 times greater for the RFM radio. At some power levels, the transmit power is smaller than the receive power (figure 2).

5. REFERENCES

[1] ns-2 simulator, http://www.isi.edu/nsnam/ns

[2] Wireless Integrated Networks Systems (WINS), http://wins.rsc.rockwell.com

[3] http://www.cs.berkeley.edu/~jhill/tos/

[4] DR3000 ASH Radio Module, http://www.rfm.com/products/data/dr3000.pdf