Busting Myths of Energy Models for Wireless Sensor Networks

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When developing and validating algorithms and protocols for Wireless Sensor Networks, simulations provide valuable insights that would be impractical to gather from real world experimental deployments. For these simulations to be meaningful, realistic models of the way energy is consumed in the targeted sensor devices need to be produced. In this letter, we identify a number of inaccuracies to avoid when constructing simulation energy models and in doing so draw attention to a device specific behaviour with the potential to invalidate research assumptions.

Introduction: Energy consumption is a preoccupation for Wireless Sensor Network (WSN) researchers whether the devices of interest are battery powered, harvest energy from the environment, or utilise some hybrid of the two. Put simply, the more energy the devices use, the less useful they become over time. When simulating WSNs to evaluate potential advances in sleep scheduling algorithms, low-power listening protocols, and opportunistic forwarding schemes to name just a few areas of active research, having a realistic model of how the devices under test consume energy is essential. But creating these energy models appears to be error prone. A number of "myths" have emerged in stated or implicit assumptions about how WSN devices work. As the most power hungry component, most of these invalid assumptions concern the radio transceiver. In this letter, we examine two commercially available WSN devices and demonstrate that a number of oft repeated myths are invalid, at least, they are for the devices under test. It should be noted that references in this letter to research relying on "busted myths" are given solely to demonstrate that had we undertaken the same research on the devices we use, one or more basic assumptions would have been invalid. The original authors, however, may have had other devices in mind where their assumptions would indeed hold.

Evaluation Setup: A simple transmitter/receiver application was developed in NescC & TinyOS and cross compiled for the two commercially available low-power WSN devices we use most often in our research, viz., the TelosB compatible Advanticsys MTM-CM5000-MSP and the Unicomp UCMote Mini. On initialisation or reset the transmitter waits a couple of seconds before energising its transceiver then waits a few more seconds before starting a 25 ms self-restarting timer to repeatedly broadcast an unencrypted 14 *byte* packet made up of standard TinyOS / IEEE 802.15.4 headers and a 2 *byte* payload. The receiver also waits a couple of seconds before energising its transceiver. On receipt of a packet broadcast by the transmitter, the receiver does nothing beyond assigning the value of the 2 *byte* payload to a program variable. Both WSN devices and all measuring equipment were powered on for an hour before readings were taken to ensure everything was functioning at normal operating temperatures. The room temperature was 25.2 °C. For resistor shunt evaluations, the cable used was assessed to have a resistance of 1 mΩ and the resistor plus cable was measured at 10.011 Ω making the resistor 10.01 Ω.

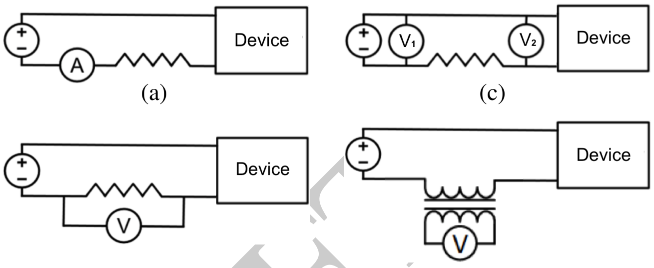
Measuring Current Draw: To create an accurate energy model of a WSN device, it is fundamentally important to have measurements of how much current is drawn by the devices being modelled when the transceiver is switched off, when it is transmitting a packet, when it is receiving a packet, and when energised but neither transmitting nor receiving; this last state being know as "idle listening" [3]. We have traditionally used Ohm's Law ($I = V/R$) and a simple shunt resistor circuit to measure current draw, but on a number of occasions research colleagues have expressed an opinion that this technique is perhaps too simple to produce accurate results, even suggested the technique had been "discredited". To ascertain the accuracy of these claims, four additional measurement techniques where trialed to calculate the current draw when an MTM-CM5000-MSP is transmitting and receiving a 14 *byte* packet:

Ammeter: Easiest method (Fig. 1(a)); simply insert in the circuit and note the measured current. Ammeter used was an Agilent U3402A digital multimeter.

Voltage drop across resistor shunt: Our traditional method (Fig. 1(b)); if voltage drop is measured with an oscilloscope, timed traces can be captured to see how long devices stay in a particular state. Ohm's Law allows direct calculation of the drawn current if the voltage and resistance are known. Voltmeter used was an Agilent DSOX2024A oscilloscope.

Voltage before and after resistor shunt: Instead of measuring voltage drop across the resistor, the voltage before and after the resistor are measured (as shown in Fig. 1(c)) using the Agilent U3402A digital multimeter and the Agilent DSOX2024A oscilloscope. The Ohm's Law calculation becomes $I = (V_1 - V_2)/R$.

Hall-effect sensor: We replaced the shunt resistor with a Honeywell CSLW6B40M, an open-loop current sensor with a sensitivity of 25.500 mV/A over a ±40 mA range; see Fig. 1(d). The manufacturer's datasheet quotes resistance of the hall-effect sensor as 120 Ω but when measured, the value was 87.067 Ω giving a sensor plus wire resistance of 87.068 Ω. Hall-effect sensor evaluation was undertaken with automatic and manual calibration.



(a) (c)

(b) (d)

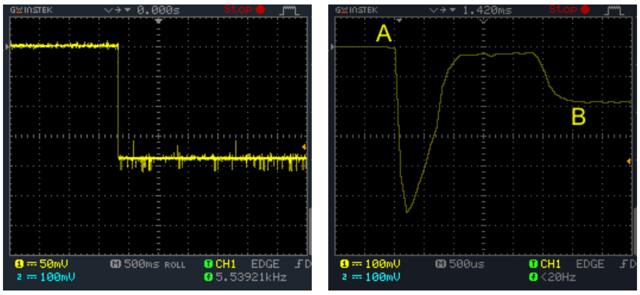
Fig. 1: Current draw measurement circuits: (a) ammeter, (b) resistor shunt voltage drop, (c) dual voltmeter/scope, (d) Hall-effect sensor.

Table 1: Current draw by measurement technique, MTM-CM5000-MSP

Technique	Transmit	Receive
Manufacturer's Datasheet	18.8 mA	17.4 mA
Ammeter	19.0903 mA	19.069 mA
Resistor Shunt Voltage Drop	19.116 mA	19.216 mA
Pre and Post Shunt Voltage	19.031 mA	19.306 mA
Hall-effect - Auto Calibration	19.461 mA	19.510 mA
Hall-effect - Manual Calibration	18.986 mA	18.934 mA

Results of these evaluations shown in Table 1 clearly indicate that there is little difference between measurement techniques, with no more than 2.5% variation in the results.

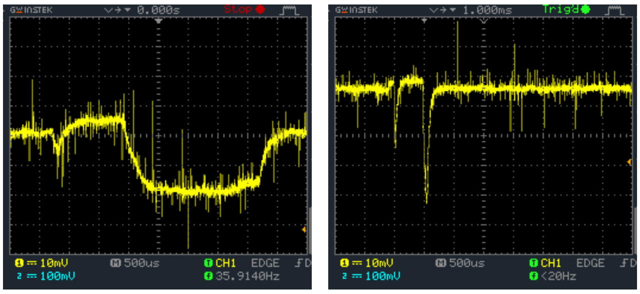
Transceiver Warm Up: It can be tempting to assume energising the transceiver in a WSN device occurs instantaneously and for no energy cost; the voltage drop trace in Fig. 2(a) would appear to support this theory. However, if the sample rate on the oscilloscope is increased by three orders of magnitude it becomes clear that it takes a finite time for the transceiver to become available, and during that time the energy consumed is approximately equivalent to the energy required to transmit a 14 *byte* packet. Point A in Fig. 2(b) shows the timer kicking in, the transceiver not being ready for use until point B.



(a) (b)

Fig. 2: Voltage drop across resistor shunt for timer based activation of the CC2420 transceiver on an MTM-CM5000-CSP, (a) 500 ms sampling and (b) 500 µs sampling.

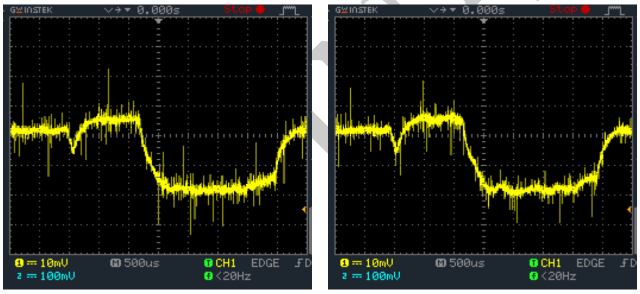
Idle Listen vs Transmit & Receive: Manufacturer's datasheets can be misleading; the one for our MTM-CM5000-CSP devices does not give a figure for idle listening, i.e. when the transceiver is energized, but neither transmitting nor receiving. A comprehensive paper on energy models for WSN devices [4] gives the "idle" power consumption of the CC2420 transceiver as 426 µA. While the accuracy of this value cannot be determined, our measurements show that when embedded in the MTM-CM5000-CSP, the entire device consumes approximately 19 mA when idle listening. From Fig. 3(a) it is clear that whilst receiving a packet increases the energy consumption of an MTM-CM5000-CSP device by around 10%, it only does so for little more than 1 ms and the device then returns to its idle listen current draw until the next packet is received. In the test system, packets are sent once every 25 ms meaning increased energy consumption of reception is experienced just 4% of the time. Hence, the total additional cost of receiving packets over simple listening for them, in this scenario, is only 0.4%. Fig. 3(b) shows the additional cost of receiving packets on the UCMote Mini is even lower.



(a) (b)

Fig. 3: Voltage drop across resistor shunt receiving a 14 *byte* packet, (a) MTM-CM5000-CSP and (b) UCmote Mini

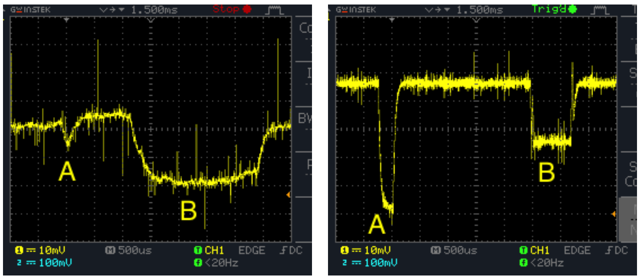
Effect of Reducing Transmit Power: Transmission Power Control (TPC) schemes for WSNs have been of interest with many active research projects [5]. In 2014, Transmission Power Control-based Opportunistic Routing (TCOR) was proposed [6]. Amongst TCOR's assumptions is that transmitting at a low power level consumes less energy than transmitting at higher power. On the devices we use, this is simply not the case. Fig. 4 shows the resister shunt voltage drop charts for the same MTM-CM5000-MSP sending a 14 *byte* packet at maximum and minimum transmit power. Whilst the communication range is significantly different in each case, the energy consumed by the device is clearly unchanged.



(a) (b)

Fig. 4: Voltage drop across resistor shunt sending 14 *byte* packet at (a) maximum and (b) minimum transmit power, MTM-CM5000-CSP with CC2420 transceiver.

Device Differences: Although small low-power WSN devices have similar aims and conform to internationally recognised communication standards, they vary significantly in their power consumption profiles. Manufacturer's choices of micro-controller, memory module, and radio transceiver create devices that vary significantly from one another in implementation, if not intent. Fig. 5 clearly shows the differences between the devices we evaluated when sending a packet. The UCMote Mini has an idle listen current draw of 13 mA, which is 30% lower than the MTM-CM5000-CSP. Conversely, the UCMote Mini uses significantly more energy handling the timer interrupt (point A on Figs. 5(b) and 5(a)). When transmitting the packet (point B on Figs. 5(b) and 5(a)) the UCMote Mini draws as much *additional* energy over its idle listen consumption, but it does so for less than one third the time the MTM-CM5000-CSP is consuming extra energy above its idle listen state.



(a) (b)

Fig. 5: Voltage drop across resistor shunt responding to a timer (point A) and sending 14 *byte* packet (point B) from (a) MTM-CM5000-CSP with CC2420 transceiver and (b) UCMote Mini with ATMega128RFA1 integrated transceiver, both at default (maximum) transmit power.

Conclusion: We have shown that evaluating current draw via voltage drop across a resistor shunt is just as effective a measurement technique as more complex methods, and identified a list of inaccuracies to avoid when adopting WSN energy models for simulations. From our findings, we consider the following WSN energy model myths "busted":

Sending a packet is the most energy hungry operation: No, sending a packet is not. Keeping the transceiver on for idle listening is far more expensive.

Turning on the transceiver on is instantaneous: No, it is not instantaneous. There is a significant warm up time that can consume as much energy as sending a packet.

Decreasing transmit power uses less energy: No, it does not. If the transceiver is already energized, you draw the same current regardless of transmit power.

Generic energy consumption models fit all devices: No, they do not. We have demonstrated significant differences in energy consumption between similar devices from different manufacturers.

It should be noted that whilst reducing transmit power does not save energy at the individual device level, the corresponding reduction in transmission range may realise reduced energy consumption across the extended network if doing so reduces unnecessary processing and re-transmission of overheard packets. However, as we have shown, idle listening dominates energy consumption in WSNs so reducing transmission range may not save a significant amount of energy. In this and all WSN scenarios, it is obvious that realistic, device-specific energy models are fundamental to meaningful simulations.

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References

1 Ye, W., Heidemann J. and Estrin D.: 'An energy-efficient MAC protocol for wireless sensor networks,' in Proceedings of INFOCOM, New York, NY, USA, pp. 1567-1576, June 2002.
2 Zhou, H. Y. Luo, D. Y., Gao, Y ,and Zuo, D.C.: 'Modeling of node energy consumption for wireless sensor networks' Wireless Sensor Network, vol. 3, no. 1, p. 18, 2011.
3 Khemapech, I., Miller, A. and Duncan, I.: 'A survey of transmission power control in wireless sensor networks' in Proceedings of the 8th Annual Postgraduate Symposium on the Convergence of Telecommunications, Networking and Broadcasting, Liverpool, U.K., pp. 15-20, June 2007
4 Coutinho, R. W., Boukerche, A., Vieira, L. F., and Loureiro, A. A.: 'Transmission power control-based opportunistic routing for wireless sensor networks' in Proceedings of the 17th ACM International Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems (MSWiM), Montreal, QC, Canada, pp. 219-26, September 2014