µMobile IPv6 in Wireless Sensor Networks

R. Custódio, R. Silva, J. Sá Silva, D. Nunes and Fernando Boavida
Depart. of Informatics Engineering
University of Coimbra
Coimbra, Portugal
sasilva@dei.uc.pt

Carlos Herrera
Departamento de
Electrónica y Telecomunicaciones
Escuela Politécnica Nacional
Quito, Ecuador
carlos.herrera@epn.edu.ec

***Abstract*— In the new era of Internet of Things, wireless sensor networks (WSNs) can provide a new way of communication between the Virtual and the Real World. However, mobility has become more and more important in flat WSNs allowing them to expand to new concepts and extending their applicability. Meanwhile, it is also crucial to control losses and support quality of service in these mobile environments. In fact, this is very important for monitoring people's health conditions in hospitals, in military scenarios and in dangerous industrial environments. However, so that an end-user application can take advantage of a mobility scenario, a low level mobile protocol should be implemented in a transparent way for applications. This article presents the implementation details and some evaluation studies of two mobility models for WSNs: one based on the well-known MIPv6 and another one based on our previous work in draft-silva-6lowpan-mipv6.**

Keywords*— *wireless sensor networks, mobility, 6LoWPAN, MIPv6

I. Introduction

Wireless Sensor Networks (WSNs) are composed by a variable number of electronic small devices (motes), with onboard or external components that may have the capability of processing, sensing, actuation and communication in an ad hoc approach. They are an effective structure of monitoring and observing physical phenomena that allow the gathering of high-resolution data, in remote locations. The absence of human presence allowed by WSNs can also be relevant for the monitoring phenomena, because motes are small, discreet and go by unnoticed.

For those reasons, academies, military organizations and industries have raised their interest for using and adapting WSNs to many different scenarios. Their suitability to operate in hostile, extreme, remote, and dangerous environments for humans shows that motes can be used beyond static scenarios. In fact, mobility is a new requirement that can introduce novel concepts and expand flat WSNs.

This article proposes and compares two mobility models for WSNs. One is the Mobile IPv6 [6] adapted to WSNs, and other is µMIPv6 proposed by the authors in the draft-silva-6lowpan-mipv6 [7]. To test them, we used the Contiki 2.5-rc1 Operating System (OS) [14] with the minimum modifications needed. Both models were developed without using any host to control mobility, being the Contiki OS responsible for all mobility procedures.

Section 2 approaches Mobility in WSNs, which includes the Related Work in the area. Section 3 presents the µMIPv6 model that we proposed in an IETF draft, while in section 4 we give an overview of Contiki OS, MIPv6 and other considerations that were necessary to perform testing. The tests and achieved results can be found in section 5, and finally, conclusions and future work are presented in section 6.

II. Mobility in WSNs

A. Related work

Ali et al. [8] proposed a cross layer mobility architecture without using IP protocol for Contiki OS. Their work was based on the need of a mobility solution for medical and disaster scenarios. Also, they claimed that their proposal is generic enough to be applied to any sensor network. However, this implementation presented several limitations and it is neither included in Contiki OS, even in its last release (2.5-rc1), nor available to download or test.

Currently, there are already some mobility models for the MAC or Networks Layers in WSNs. MS-MAC[9], MAMAC [11] and MH-MAC [12] are examples of MAC protocols designed to match evolved duty cycle methods with mmobility support. However, this combination ended in complex and energetically demanding solution, unsuitable for WSNs.

Camilo et al. [13] proposed an evaluation of three known mobility models, and adapted them to WSNs using TinyOS. Connectivity, nomadism and MIPv6-based models were tested using real motes and using a computer linked to the base station to generate ICMPv6 packets for testing. A proposal of a compressed MIPv6 with foundations in 6LoWPAN is presented by Silva et al. [4] and detailed in draft-silva-6lowpan-mipv6 [7].

In WSNs, the use of the IP protocol has always been considered inadequate due to the fact that it does not minimize memory usage or processing. Moreover, the use of full TCP/IP mechanisms is not possible because it requires more resources than the devices can offer. However, the integration of IP has the advantage of offering a transparent communication between nodes, providing interoperability and even Internet connectivity. Moreover, the need for translation gateways and similar devices is no longer necessary [13].

To the use of IP to become feasible in WSNs, IETF created the 6LowPAN group [18], that has been working on standards proposing the transmission of IPv6 packets over low capability devices in wireless personal areas, using IEEE 802.15.4 radios. They worked on an overview, assumptions, problems and goals for improving IPv6 over low power wireless PANs, and launched RFC 4919 [19]. Also made the RFC 4944 [20], that specifies many adaptations from IP to LoWPAN. Some examples are: packet formats and interoperability; addressing schemes and management; network management; routing in dynamically adaptive topologies; security (set-up and maintenance); discovery of devices and services.

Considering the complexity of supporting mobility at the MAC Layer, we consider that the solution should comprise an adaptive MAC Layer with mobility explicitly supported at the Network Layer. Re-using existent knowledge from conventional IP networks, such MIPv6 [3], should be considered and thus we aim to evaluate and compare the impact of such in WSNs.

III. µMIPv6

Silva et al.[7] proposed µMIPv6 as a lightweight solution for mobility in WSNs. This solution proposes a set of compressions and protocol simplifications regarding MIPv6 RFC 3775, following the same rules used to adapt IPv6 packets to IEEE 802.15.4 frames, as presented in RFC 4944.

µMIPv6 is a generic layer 3 mobility solution for LoWPAN, that guarantees a controlled latency in the mobility procedure. The mobility header is compressed from 48 bits to 8 bits and the following message Binding Update or Binding Acknowledge now requires only 16 bits instead of 48 bits. A transmission of a mobile message (mobile header plus BU or BA) takes less 72 bits than RFC 3775. Moreover, the messages used in the return routeability feature are compressed in order to be used in LoWPAN, providing some security in communications between a MN and a correspondent node (CN), also avoiding triangulation.

IV. Evaluation Basis

We implemented MIPv6 and µMIPv6 for the actual version of Contiki OS - 2.5 rc-1 and changed the original OS to make it more lightweight in order to handle mobility

A. MIPv6

This mobility protocol assumes the existence of a home network (HN) where the MN is considered to stay. Other networks are called foreign networks (FN) where the MN can move to.

In the HN there is one node responsible for the mobility management called HA. This node always knows the location of every MN that is away from home, and is responsible to catch and forward every packet on the network directed to them. The HA's internal table containing this information is called Binding Cache Table.

Figure 1 presents a mobility request from a MN when it is in a FN. The four messages depicted are the mandatory ones to perform a mobility request. The node gets information from the FN, such as the IP prefix, in order to inform the HA of its current IP address. When a MN detects that it is going to lose connectivity within the actual network it sends a Routing Solicitation (RS) to know which routers are around. The received response, Routing Advertisement (RA), has a prefix information option that is used to advertise the IP prefix of the corresponding network. Based on the prefix and the MN's MAC address, a new IPv6 address is created and used in the Binding Update (BU) message to HA, so that the HA can change MN's binding cache entry and update it with a new address. After that, HA sends a Binding Acknowledge (BA) with the status of BU, indicating if the request was accepted or rejected.

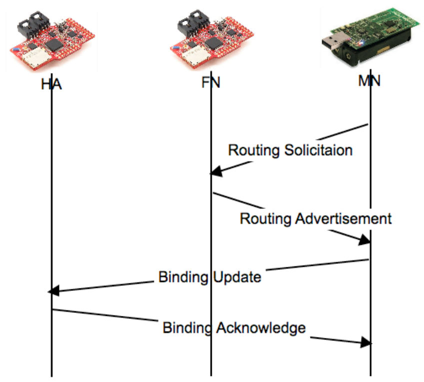

Figure 1. Mobile request in detail.

B. Draft-silva-6lowpan-mipv6 (µMIPv6)

We only implemented the basic messages for mobility support according to µMIPv6 (Figure 1), and we did not implement the return routeability process in order to keep mobility as simple as possible.

As described before, the main difference between MIPv6 and µMIPv6 is the length of the messages, which were reduced in µMIPv6 to approx.

V. Evaluation of the Proposed Model

This section presents the performance achieved by our µMIPv6 model after being submitted to a range of scenarios.

In a top down approach, our tests measured several characteristics: packet losses, energy consumption, and elapsed time under the following circumstances:

- MIPv6 and µMIPv6 were tested under the same conditions in order to perform a direct comparison between both approaches.
- Tested both hard and soft handoffs; to simulate realistic situations, HN and FN always used different domains, and were in the same channel for soft handoffs, and in different channels for hard handoffs.

- Tests performed while running a ping application during the handoffs to quantify packet loss.
- Some tests used only the necessary motes for mobility while other tests used extra motes to generate additional traffic on both networks.

A. *Scenarios*

When a MN travels between networks, one of two possible situations can happen: soft handoff and hard handoff. Soft handoff is when the MN can directly change messages with HA in a FN. In hard handoff, the MN cannot change messages directly, forcing them to be routed to the HA. To evaluate such we focused our experience in a conventional network scenario, composed by two distinct WSNs and motes moving between them. Besides, our experience also targeted a more complex scenario in which local motes are loading the network with collateral communications. Figure 2 depicts the basic scenario, while Figure 3 presents the same network with the extra load. The hardware used in these experiments was the Zolertia Z1 motes [15].

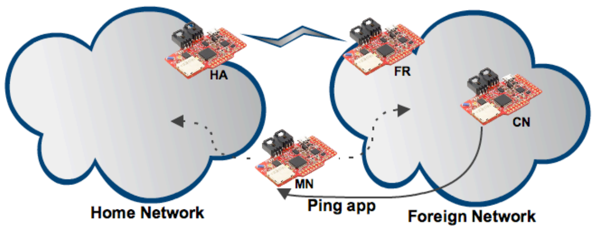

Figure 2. CN pinging MN and MN movement; without extra load.

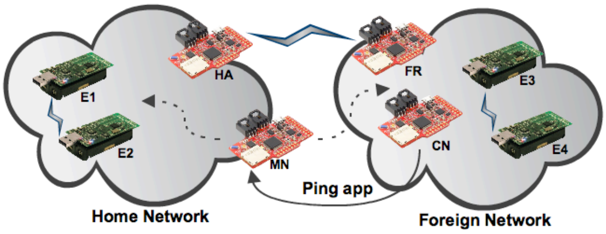

Figure 3. CN pinging MN and MN movement; with extra load.

To test hard and soft handoffs we take advantage of the channel that is set to each network. If channels are equal, a soft handoff is made. If channels are different, the HA and the FR need to catch every message whose destination is not within in their own network, changing to the correspondent channel and forwarding the message to its destination.

For each scenario we tried to answer the following questions: how many packets are lost during the handoffs? How much time is needed? How many handoffs are successful?

B. *Tests with hard and soft handoff*

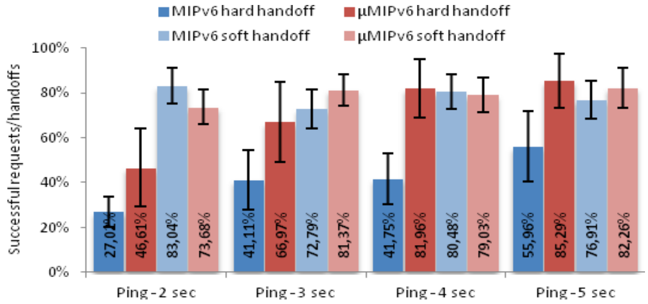

Figure 4. Successful mobility requests/handoffs in Figure 2.

Figure 4 presents the results of Figure 2 regarding successful requests and handoffs.

This chart shows, on each column, the successful percentage of requests that took less than 5 sec. After a successful request, the MN changes to the other network, performing a handoff. Since the networks could either be on the same or in different channels and we can either test MIPv6 or µMIPv6, there are a total of four possible combinations to be tested. At the same time, the CN is pinging the MN using different ping rates i.e., from 2 seconds to 5 seconds, which are represented on each cluster of the chart.

Figure 5 presents the average losses in soft and hard handoff with the MN responding to pings from the CN. We considered a loss when one ping sent from CN does not return the respective response (pong), and that includes the loss of an echo request or an echo reply in the communication.

µMIPv6 performs quite better when compared with the MIPv6 implementation, especially in hard handoff, reaching twice the performance of MIPv6 in some cases.

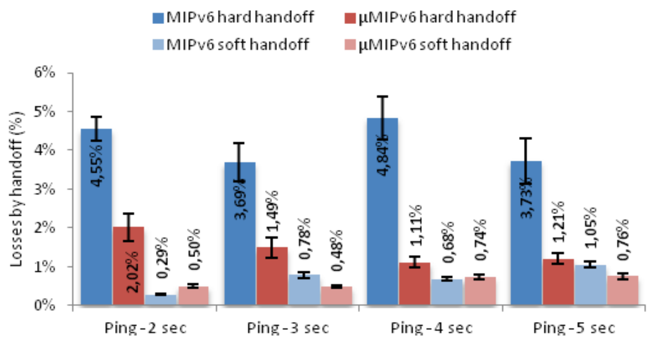

Figure 5. Percentage of ping losses by handoff in Figure 2.

Table I presents the conversion from one ping lost to its percentage, according to the ping rate used from the CN to the MN. To convert percentage in pings, the corresponding cluster from Figure 5 and column from Table I should be used.

Table I Converting one packet lost in percentage for each ping generation interval.

Ping generation	*2 sec*	*3 sec*	*4 sec*	*5 sec*
% of 1 packet lost	1,33%	2,00%	2,67%	3,33%

We analyzed the time spent on each mobility request by comparing Figure 6 with the baseline. We can view that all components rose their time due to the fact of CN now pings MN. The time spent on a mobility request suffers a greater impact on MIPv6 when using hard handoff. Under these conditions, it can take from half to a full second longer to perform a mobility request.

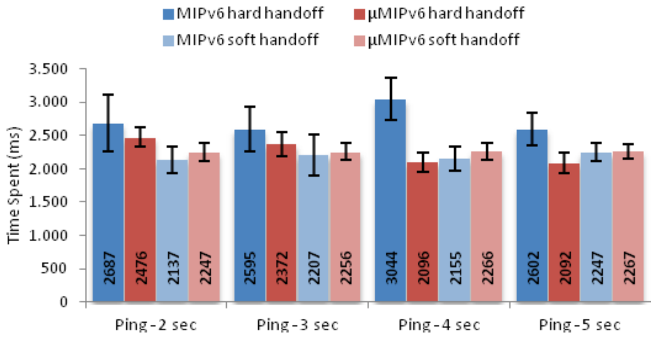

Figure 6. Average time spent on each mobility request in Figure 2.

In terms of energy, Figure 7 was expected to present higher values due to the increase of communications performed by the MN and the CN. Despite in the Ping-3sec, MIPv6 was always more demanding from the energetically point of view. It is also important to notice that µMIPv6 has less variation of energy spent than MIPv6.

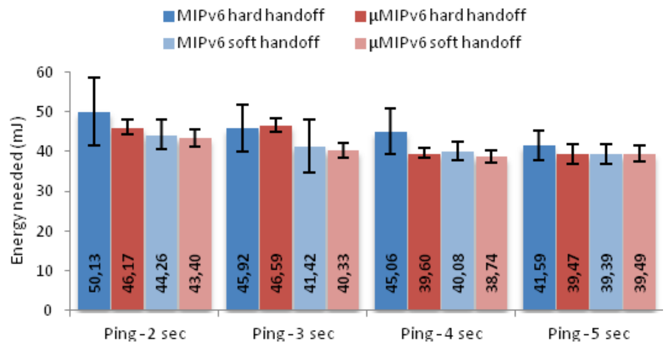

Figure 7. Average energy needed on each mobility request in Figure 2.

C. Tests with hard and soft handoff with extra load

This section presents the results achieved in Figure 3's scenario. Comparatively with Figure 2, we added some extra nodes to the network to test both models under more intensive traffic. We used a similar approach as before, to allow a direct comparison between both scenarios.

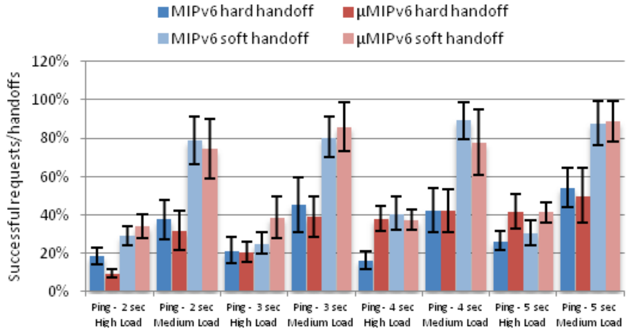

Figure 8. Successful mobility requests/handoffs in Figure 3.

On Figure 8, each cluster now represents not only the ping rate use by CN to MN, but also the ping rate between the two extra motes on each network (marked as Load). This means that, for each ping rate from the CN to the MN, we have two clusters that represent the 5 sec and 10 sec ping rate of additional traffic by the motes E1 to E4.

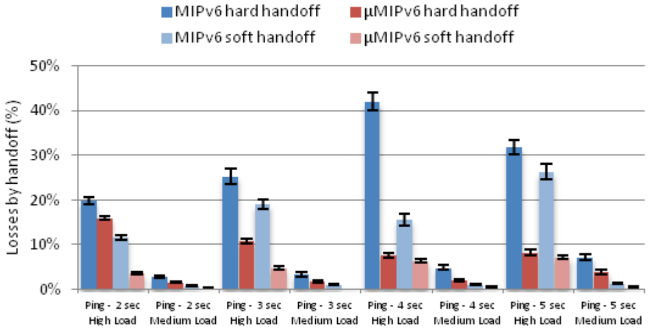

Figure 9. Percentage of ping losses by handoff in Figure 3.

As we can see in Figure 9, in some of the cases we have many losses by handoff. This happens because many pings were lost and few mobility requests succeeded, which leads to higher losses by mobility request. Also, µMIPv6 is once again better than MIPv6, by losing fewer packets.

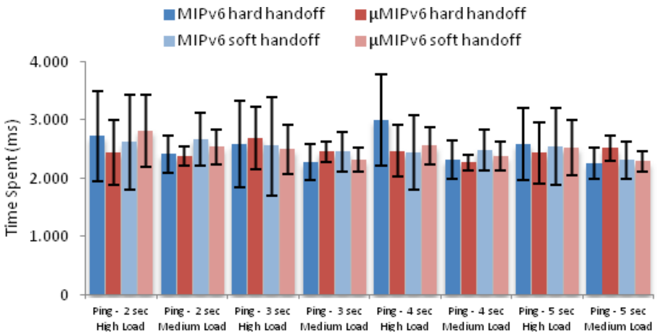

Figure 10. Average time spent on each mobility request in Figure 3.

Regarding time spent with mobility requests (Figure 10), both models need about 2,5 seconds to perform the request. In general µMIPv6 is faster than MIPv6.

In Figure 11 it is shown the energy spent on each request with additional network. Looking at the figure we might see that hard handoff presents a lower consumptions than soft handoff. However, we should have in mind that these results are in consideration to the number of successful request/handoffs (Figure 8), and therefore the means are not directly comparable.

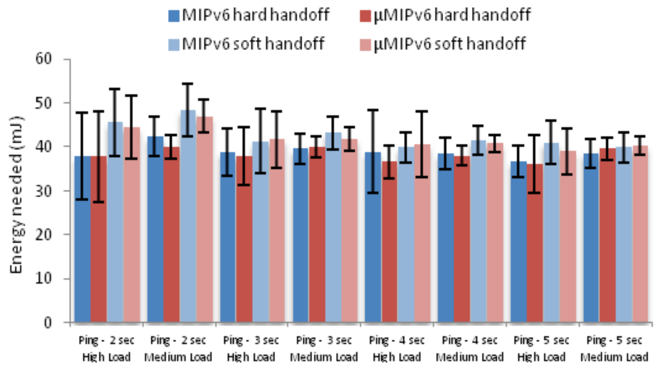

Figure 11. Average energy needed on each mobility request in Figure 3.

D. *Resume of the evaluation*

The next two tables resume all the tests presented so far, with the average results of µMIPv6 and MIPv6. Each table contains two lines: Without load, that corresponds to Figure 2, and with High Load, that is the 5 sec ping interval for motes E1 to E4 from Figure 3.

µMIPv6

Soft handoff	*Losses (%)*	*Time (ms)*	*Energy (mJ)*
W/O Load	1,00%	2259	40,49
High Load	5,50%	2595	41,36

Hard handoff	*Losses (%)*	*Time (ms)*	*Energy (mJ)*
W/O Load	1,46%	2259	42,96
High Load	10,68%	2507	37,07

MIPv6

Soft handoff	*Losses (%)*	*Time (ms)*	*Energy (mJ)*
W/O Load	0,70%	2187	41,29
High Load	18,13%	2536	41,88

Hard handoff	*Losses (%)*	*Time (ms)*	*Energy (mJ)*
W/O Load	4,20%	2732	45,68
High Load	29,74%	2719	38,01

VI. Conclusions and Future Work

This paper presented one of the few existent evaluations of MIPv6 in WSNs, evaluating not only its performance on such constrained devices but also comparing it with one of the unique proposals of an enhanced light version of the same protocol, the µMIPv6.

Both protocols were implemented in ContikiOS-2.5-rc1 and both were evaluated under the same conditions. In general, both solutions were capable to run in such constrained hardware, with the µMIPv6 proposal achieving slightly better results. However, the difference was not significantly and none of these solutions performed great. Therefore, in front of such results, we can conclude that node-based solutions should be replaced in future work by network-based solutions, where the main load of the process is supported by powerful nodes on behalf of the tiny, hardware constrained sensor nodes.

Acknowledgment

The work presented in this paper was partially financed by the iCIS project (grant CENTRO-07-ST24-FEDER-002003).

References

[1] R. Silva, J. Silva, and F. Boavida, "Towards Mobility Support in Wireless Sensor Networks," *CRC'10, ISBN: 978-989-96929-1-6*, Oct. 2010.

[2] D. Puccinelli and M. Haenggi, "Wireless sensor networks: applications and challenges of ubiquitous sensing," *Circuits and Systems Magazine, IEEE*, vol. 5, no. 3, pp. 19–31, 2005.

[3] D. Johnson, C. Perkins, and J. Arkko, "RFC 3775: Mobility support in IPv6," *IETF, June*, 2004.

[4] R. Silva and J. Sa Silva, "An adaptation model for mobile ipv6 support in lowpans," *draft-silva-6lowpan-mipv6-00*, p. 25, 2009.

[5] M. Ali, T. Voigt, and Z. A. Uzmi, "Mobility management in sensor networks," *MSWSN/2nd DCOSS*, 2006.

[6] H. Pham and S. Jha, "Addressing mobility in wireless sensor media access protocol," in *Intelligent Sensors, Sensor Networks and Information Processing Conference, 2004. Proceedings of the 2004*, 2004, pp. 113–118.

[7] W. Ye, J. Heidemann, and D. Estrin, "Medium access control with coordinated adaptive sleeping for wireless sensor networks," *Networking, IEEE/ACM Transactions on*, vol. 12, no. 3, pp. 493–506, 2004.

[8] L. Bing, Y. Ke, Z. Lin, and Z. Huimin, "MAC Performance and Improvement in Mobile Wireless Sensor Networks," in *Software Engineering, Artificial Intelligence, Networking, and Parallel/Distributed Computing, 2007. SNPD 2007. Eighth ACIS International Conference on*, 2007, vol. 3, pp. 109–114.

[9] L. Bernardo, R. Oliveira, M. Pereira, M. Macedo, and P. Pinto, "A Wireless Sensor MAC Protocol for Bursty Data Traffic," *Personal, Indoor and Mobile Radio Communications, 2007. PIMRC 2007. IEEE 18th International Symposium on*, pp. 1–5, 2007.

[10] T. Camilo, P. Pinto, A. Rodrigues, J. Sa Silva, and F. Boavida, "Mobility management in IP-based Wireless Sensor Networks," *World of Wireless, Mobile and Multimedia Networks, 2008. WoWMoM 2008. 2008 International Symposium on a*, pp. 1–8, 2008.

[11] IETF, "IPv6 over Low power WPAN (6lowpan) - Working Group," *datatracker.ietf.org/wg/6lowpan/charter/*. [Online]. Available: http://datatracker.ietf.org/wg/6lowpan/charter/. [Accessed: 05-Jul.-2011].

[12] G. Montenegro, N. Kushalnagar, and J. Hui, *RFC 4919: IPv6 over low-power wireless personal area networks (6LoWPANs): Overview, assumptions, problem statement, and goals*. 2007.

[13] N. Kushalnagar, G. Montenegro, and D. Culler, "RFC 4944: Transmission of IPv6 Packets over IEEE 802.15. 4 Networks," 2007.

[14] A. Dunkels, “The Contiki Operating System - See the Power Consumption of your Tmote Sky in Real Time (Updated 13 Nov 2007),” *sics.se/contiki*. [Online]. Available: http://www.sics.se/contiki/current-events/see-the-power-consumption-of-your-tmote-sky-in-real-time.html. [Accessed: 05-Jul.-2011].

[15] ZOLERTIA, “Z1_RevC_Datasheet,” pp. 1–20, 2010.

[16]