From Training to Projects: Wireless Sensor Networks in Africa

Marco Zennaro
Telecommunications/
ICT for Development Laboratory
The Abdus Salam
International Centre for Theoretical Physics
Trieste, Italy
Email: mzennaro@ictp.it

Antoine Bagula
ISAT Laboratory
Department of Computer Science
University of Cape Town
Cape Town, South Africa
Email: bagula@cs.uct.ac.za

Mayamiko Nkoloma
Department of Electrical Engineering
Malawi Polytechnic
Blantyre, Malawi
Email: mnkoloma@poly.ac.mw

***Abstract*—Wireless Sensor Networks have a great role to play in Developing Countries. This paper reports on training workshops jointly organized by the Abdus Salam International Centre for Theoretical Physics and the University of Cape Town in South Africa (March 2010), Kenya (June 2011) and Ghana (December 2011) on Wireless Sensor Networks. The trainings were 4 days long and targeted 20 participants, composed of researchers, professionals and students from both computer science and other scientific faculties. The training activities were regional ones and used open wireless sensors for the advantages they present. The lectures were organized with theoretical lectures in the morning and laboratory sessions in the afternoon. Participants from the workshops have deployed wireless sensor networks in their own countries and have come up with some interesting applications.We will describe an application deployed in Malawi.**

I. Introduction and Purpose

A Wireless Sensor Network (WSN) is a self-configuring network of small nodes, also known as motes, deployed in quantities to sense the physical world and report to specific centre where the remote information is analyzed and processed. These tiny electronic devices can easily be integrated in our daily life to support a wide number of applications ranging from environmental, agriculture, and health care to disaster monitoring. Currently, they form the backbone of a new Internet called "Internet-of-the-Things (IoT)" that extends IP communication to enable access to IP based smart objects. For some applications such as weather monitoring for drought prediction, sensor technology is proposing a low cost weather board alternative to the static weather stations which is not only competitively much cheaper but also more flexible as it can be deployed as a fixed device or mounted on a vehicle as a mobile weather station.

We advocate the use of WSN for Development as they have many potential applications that can benefit poor communities for instance in; water quality monitoring, intelligent irrigation, landslide monitoring and many others and at the same time help in bridging the scientific divide [1].

The number of scientists in Africa, according to a 2007 report [2], is 60 for every million inhabitants. Western countries have about 5000 scientists per million inhabitants. The same report states that scientists across the whole of Africa publish about 27,000 papers in international journals per year, which is only about the same volume as those from Netherlands. If the digital divide is defined as the gap between those with regular and effective access to digital technologies and those without, then the scientific divide can be defined as the gap between those with access to scientific data and those without. We believe that the use of WSN in Developing Countries can help fill this gap with the use of low-cost and state-of-the-art solutions.

To realize these benefits, a broad portfolio of deployments will be needed as a proof of concept. It is important that the deployed networks are appropriate to the environment being investigated. They should consider both the potential scientific impact as well as the one on local society. Wider dissemination is needed to engage a greater audience for sensor development activities.

The use of WSN will also enhance Computer Science curricula in academic institutions of Developing Countries. Long-term data from sensor networks will be valuable for educational purposes and the associated tools for curricula development should be encouraged. The nodes come with the basics of a general purpose platform, but the nature of each application determines the sensing hardware specifics. Thus sensor design is a fundamental area within WSN. The ability to perform direct measurements of necessary magnitudes, to identify pattern recognition strategies and exploit computational resources appropriately represent engineering challenges that can be addressed in academia

While high-end network equipment is too expensive for hands-on training for scientists and engineers of the Developing World, the emergence of off-the-shelf low cost sensor network equipment has enabled a new training model where knowledge is acquired on real devices. This model also allows scientists and engineers, both students and professionals, to be exposed to engineering design by having planning and configuration combined with fine-tuning of equipment during the training period to meet deployment requirements. There is therefore the need for training activities focussed on the use of WSN, with a strong hands-on component, to be organized

Fig. 1. Participants from the Kenya workshop during the outdoor activity.

in Developing Countries.

II. Training Activities

The Abdus Salam International Centre for Theoretical Physics (ICTP) [3] has been active in knowledge dissemination, focusing on low-cost technologies and training of young scientists that could diffuse it further in their native regions. The mission of ICTP is to foster advanced studies and research in developing countries. The University of Cape Town is the highest ranked African university and the only African university in the top 200.

In collaboration, the institutes organized three training activities in Africa. The workshops were organized at the University of Cape Town in South Africa in March 2010, at the University of Nairobi in Kenya in June 2011 and at University of Ghana in Legon in December 2011. The trainings were 3 or 4 days long and were targeted to 20 participants, composed of researchers, professionals and students (both undergraduate and postgraduate) from both computer science and scientific faculties. An on-line application system was used to select the participants based on a competitive criterion. This resulted in highly motivated and focused group of participants. For each workshop we had 2 or 3 lecturers from ICTP, UCT and other international organizations. The training activities were regional ones, so participants came from South, East and West Africa respectively. Local organizers provided a computer room equipped with desktop computers and spotted a site for the outdoor activities, as shown in Figure 1. The workshop in South Africa was video recorded and the recordings are openly available [4]. In all the workshops a number of motes were left for the host University to be used for internal trainings.

A. Objectives

The global objective of the training activities was to provide awareness about the potentials of this new technology. The devices being low-cost and the applications dependent on the environment, the facilitators emphasized the hands-on aspects.

The specific objectives of this form of trainings were to:

1) Provide participants with a better understanding of the WSN technology in general and of the related networking concepts.
2) Provide participants with an appreciation for the interdisciplinary nature of WSN by revealing its multitude of potential applications while focusing on a particular domain knowledge relevant to the region.
3) Provide participants with an opportunity to develop practical skills through self-motivating, hands-on, team-based design activities. These skills are the same as those required by practising engineers, namely critical thinking, team-work, and good communication skills.
4) Develop a sustainable course structure and requisite infrastructure and train a future generation of trainers who will be able to expand the technology locally to create a basis for local expertise.
5) Using a regional approach, develop a sense of community among participants with the expectation of giving them the feeling of excitement about WSN and increasing interest in its application to solve local problems.

B. Curriculum

The workshops were organized with theoretical lectures in the morning and lab sessions in the afternoon. Given the smooth learning curve, participants were able to program the motes from day one, and were introduced to wireless transmissions from day two. On the last day they were given a simple but complete application, for example, to measure temperature and send the data via a wireless link. Finally a concrete discussion on applications that could benefit local communities followed at the end of sessions.

Table 1 from the South Africa workshop is an illustration of the timetable of a typical introductory 3-days training alternating lectures and laboratory exercises.

TABLE I
TIMETABLE OF THE SOUTH AFRICA WORKSHOP

Day 1 Lectures	
Introduction to WSN	2h
Open Wireless Sensors	1h
Day 1 Lab	4h
Installing the IDE	
Hello World	
Blinking LEDs	
RTC (setting the clock and the alarms)	
Temperature (reading temperature)	
Acceleration (measuring acceleration)	
Writing data on the local SD	
Day 2 Lectures	
Wireless Sensor Network Applications	1h
Networking for WSN	2h
Day 2 Lab	4h
Networking (Single hop, Multi hop,	
Transferring data from the motes to a database)	
GPRS (sending an SMS and calling a mote)	
Day 3 Lab	3h
Managing power and solar panels	
GPS (what it is and reading position)	
Day 3 Outdoor	4h
Field Activity	

C. Laboratory Component

From the laboratory component of the trainings, a number of standard projects were developed for implementation by the participants. The following projects were given and successfully executed by the participants as tasks related to the applications of sensors as fixed and/or mobile devices.

- Project 1. Monitor fridge temperature and send measurements at a predetermined interval to a computer or a mobile phone via text messages (SMS). Furthermore this activity was enhanced by sending a special alert if certain temperature ranges are attained.
- Project 2. It has been reported that in some developing countries the theft of containers during transportation from the shore to the city is common practice. Consequently, one exercise was to check container movements as it follows it's predefined itinerary. That is to say if during transportation it diverts from it's itinerary then the application should send an SMS alert with the container's GPS position and acceleration to the one in charge.
- Project 3. Check if a motor is behaving properly by measuring it's acceleration four times per second and send the information via SMS or another wireless method to a PC.
- Project 4. Measure the pollution in the city where the training is taking place. Read data every 30 seconds from a Gas Sensor board and store it on the SD card with date, time and position while sending SMSs to a given number when pollution reaches given threshold values.
- Project 5. Monitor weather to support meteorology and agriculture in the city where the training is taking place. Read data every 2 minutes from a weather board and store it on the SD card with date, time and position while sending SMSs to a given number when weather conditions in the area reach given threshold values.

The tasks involved in these projects are both indoor and outdoor and require designing the WSN and implementing a WSN prototype. These tasks successfully executed by the participants using the Waspmote platform reveal how sensors can be used as fixed and mobile devices sending and receiving SMS and uploading data on a web portal.

D. Technology

It was decided to use open wireless sensors for the advantages they present: low cost, customization and independence from one vendor [5]. In particular, the Waspmote from Libelium [6] was adopted. The advantage it offers is that it is built with a modular design. In some lab sessions GPRS boards were used to send SMS, while in other sessions Zigbee modules were adopted. In South Africa a Gas module to monitor pollution was appropriate, while in Kenya a Libelium Weather Station to monitor temperature, humidity and pressure as shown in Figure 2 were chosen. This modular design, the openess of the system, the low cost and the simple API convinced the facilitating team to use Libelium's product. In Kenya an engineer from Libelium was invited to give some lectures and practical hands on techniques.

Fig. 2. The Waspmote from Libelium with a GPRS board and Weather Station module.

E. Evaluation

To evaluate the success of the workshops, we considered different parameters including 1) regional outreach defining the diversity of participants from the region where the training is held, 2) the rejection rate expressing the percentage of applicants who were not accepted for the workshop 3) the quality of participants expressing the number of participants with a high potential to expand the knowledge after training and 4) feedback from participants. The results from different workshops we organized were satisfactory as they revealed:

- A high interest in the WSN topic: a large number of applicants were rejected from the workshop.
- Good quality of participants: the majority of selected participants have applied what they learned to solve a specific real-life problem.
- A high regional and local outreach revealed by the regional diversity (number of countries represented in the workshop) and local diversity (number of regions/localities of the hosting country which are represented in the workshop).

Figure 3 shows the results of the Evaluation form for the Kenya workshop. 67% of participants were very satisfied with the workshop design.

As a follow up to our training activities, post-workshop contacts have been maintained with the participants to monitor and help extend WSN deployments in their countries. As reported by the participants, some of the the barriers to such expansion include:

1) Cost of equipment
2) Ethical clearance for some of the new projects
3) Power issues at the server hosting the database

Some of our workshop participants are requesting more workshops to support new ideas relevant to their region. As an example, we had requests about tea and coffee monitoring in Africa, WSN to monitor fire in the equatorial rain forest in DRC and WSN to monitor exotic fruit growth.

III. Projects

After the workshops, the equipment has been used by students from the host Universities that participated to the

Fig. 3. Workshop Design evaluation for the Kenya workshop.

Fig. 4. Map showing air quality around Cape Town.

activity to develop some interesting ideas. In South Africa two students developed a pollution monitoring system to be installed on public buses. The system measures air quality and position via GPS, and sends the readings to a server via SMS. The air quality is visualized on Google Maps as shown in Figure 4and is available in real time. In Kenya, a PhD student developed a low cost weather monitoring system to be used in rural areas. She is conducting calibration work in collaboration with Kenyans meteorological department to compare readings from the new system with the ones from professional weather stations calibrated by the World Meteorological Organization (WMO). Building upon the training received in Cape Town in March 2010, one of the participants from Malawi developed an irrigation system that uses the technology learnt during the training to reduce water consumption. From the workshop organized in Ghana emerged the idea of a joint project between local universities, the African Association of Universities (AAU), ICTP and the university of Cape Town to develop a pollution monitoring system that caters for not only air pollution including the effects of the Harmatan but also would monitor water pollution and control flooding.

A. Academic Output

During the workshops, a time slot was allocated to identify research projects that are relevant to the country/region where the workshop is held in order to boost research and collaboration between participants. As we believe WSN can help in closing the Scientific Gap, this was an important part of

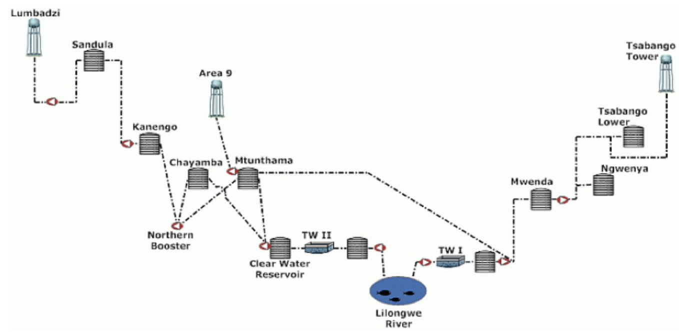

Fig. 5. Schematic of LWB's water distribution network.

the workshops. From these discussions, the following research needs were exposed :

1) Air and water pollution monitoring to identify high pollutant factories and water contamination through chemicals. The research work related to that project led to outputs [7] [8] and the open discussion led to the ideas of producing adapted energy harvesting systems for Malawi [9].
2) From the discussions held in Kenya, a project on drought monitoring emerged with research outputs produced [10][11].
3) From the open discussion held during Ghana workshop, the pollution monitoring system described earlier has been extended to include the impact of Harmattan winds in Ghana. Further discussions revealed the need to design a system that can control water tank levels on the Legon campus of the university of Ghana in Accra.

B. Tank monitoring in Malawi

This section presents a web based solution for monitoring remote water storage tanks across Lilongwe, Malawi, developed by Mayamiko Nkoloma, a workshop alumnus, in conjunction with iMoSyS [12], a recently established technological Malawian company.

Lilongwe Water Board (LWB) [13] a parastatal organization mandated to supply potable water to the city of Lilongwe in Malawi face challenges in managing the water resource for distribution. The LWB distribution network can be seen in Figure 5 One of the main contributing factors is the lack of tools for monitoring the water system from the treatment plants, distribution system and finally to the consumers, in terms of production, consumption, leakage and water quality levels.

High transportation costs, poor road network, long distance between remote water storage tanks make it more challenging for LWB technical support team to visit all facilities and effectively monitor the adequacy of water levels to meet demand. Apart from this, the traditional ways of conducting the level measurements have shown limitations in presenting accurate values and control water over flows which is a major contribution to revenue losses for the organization. Conducted to eradicate these constraints a project aimed at developing

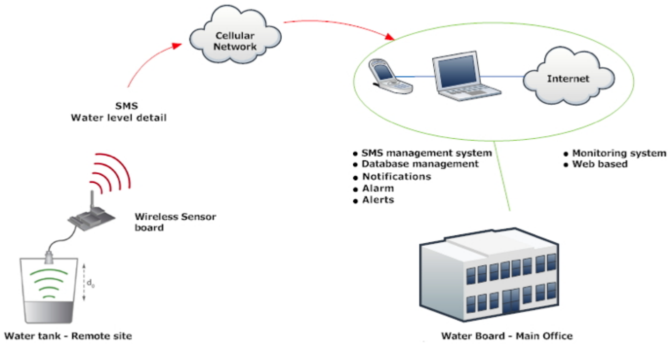

Fig. 6. A brief overview of remote system and central management set-ups.

a cost effective tank monitoring application that continuously presents remote water levels is under-way.

The project output gives LWB direct access to water levels of remote tanks through the use of wireless communication technology. Specifically, the remote tank system setup is based on wireless sensor network technology and water level readings are attained through the use of an industrial weather resistant range finder. Additionally, the mote has a GPRS module that enables data transmissions in form of SMS over cellular network to the management site at predetermined intervals.

In addition to comprehensively securing and transmitting the measurements, an open source communication server is installed at LWB office to receive and store SMSs in a database and concisely rely for graphical presentation of remote tanks trends on a web portal. As a new innovative solution that demonstrates a low cost mechanism for the water sector using the existing mobile network infrastructure, the deployed application presents the following key benefits.

1) Access to remote tank water levels from office local area network (LAN) or also from anywhere through the use of Internet.
2) Reports of water usage and production trends.
3) Alerts through SMS or email to particular technical personnel when critical tank levels are met.
4) Verification on the adequacy of water to meet demand.
5) Peace of mind provided by instant alarm notification.
6) Readily available water level data for decision making, service and maintenance planning.
7) No ongoing monitoring costs, but remote information reaches the engineers right in front of their workstation.
8) GSM communication channel attribute enables replication of the solution to other sites as long as they are in coverage of mobile service provider network.
9) Inclusion of solar electricity powering option ensures 100% system availability as the tanks have no other powering mechanisms.

Currently LWB is remotely monitoring nine tanks, namely; Lumbadzi, Sandula, Area 9, Chayamba, Mtunthama, Mwenda, Ngwenya, Tsabango Tower and Tsabango Lower. Figures 6,7, 8 and 9 show a snapshot of the monitoring portal.

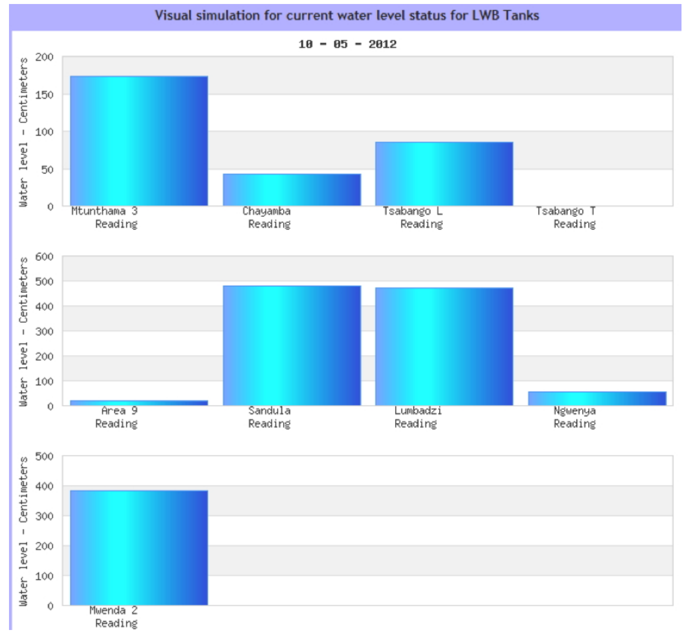

Fig. 7. A real time view of remote tanks statuses at a particular time of day.

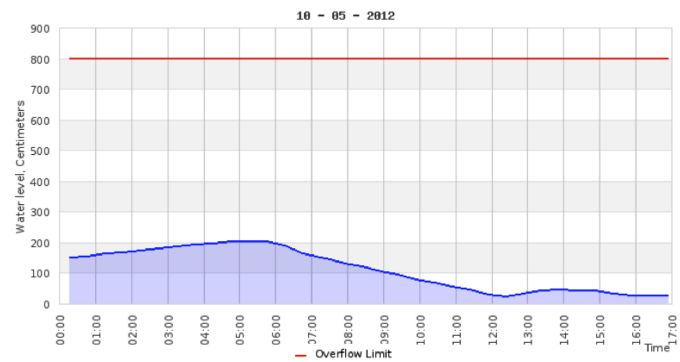

Fig. 8. A plot presenting a detailed report on water level variations for a particular day.

A tabulated summary for today's water level variations

Time	00:16	00:46	01:16	01:46	02:16	02:46	03:16	03:45	04:15	04:45	05:15	05:45	06:15	06:45
Water level(cm)	149	155	163	166	174	180	186	192	196	202	204	202	190	163
Status	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Time	07:15	07:24	07:54	08:24	08:54	09:23	09:53	10:23	10:53	11:23	11:53	12:23	12:53	13:22
Water level(cm)	152	147	132	122	106	94	77	70	57	46	31	23	33	44
Status	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Time	13:52	14:22	14:52	15:22	15:52	16:22	16:52							
Water level(cm)	45	43	43	34	25	26	27							
Status	✓	✓	✓	✓	✓	✓	✓							
Time														
Water level(cm)														
Status														

Fig. 9. An associated table of readings for a particular day.

IV. Conclusions and Future Work

The workshops have been successful as they have fostered local development of solutions that solve problems of local communities. Instead of driving participants to a specific application domain, our goal was to empower them to design their own solution. In this sense, we talk about knowledge co-creation. We gave the specific example of Malawi, where a solution was designed from local needs.

In the future workshops we will focus on IPv6 and Sensor Networks, as the interest in this new aspect of WSN is growing. Wireless sensors will become fully part of the global IPv6 network and will be accessible from everywhere in the world.

References

[1] M. Zennaro,B. Pehrson,and A. Bagula, *Wireless Sensor Networks: a great opportunity for researchers in Developing Countries*, in Proceedings of WCITD2008 Conference, Pretoria, South Africa, October 2008.

[2] Nature: African nations vow to support science, http://www.nature.com/news/2010/100623/full/465994a.html

[3] R. Struzak et al., *Wireless Sensor Networks for Environmental Monitoring in Developing Countries: A Report on the 2011 ITU-ICTP Workshop and Conference*, Radio Science Bulletin No 339 (December 2011).

[4] First Workshop on Wireless Sensor Networks with Applications in Environment Monitoring, http://www.ws4all.org/training/

[5] M. Zennaro, A. Bagula, H. Ntareme, G. Inggs and S. Scott, *On the relevance of Open Wireless sensors for NGN*, in Proceedings of the ITU-T Kaleidoscope conference, August/Sept. 2009.

[6] Libelium Waspmote, http://www.libelium.com/products/waspmote

[7] A. Bagula, M. Zennaro, G. Inggs, S. Scott and D. Gascon, *Ubiquitous Sensor Networking for Development (USN4D): An Application to Pollution Monitoring*, in Sensors, 2012, 12(1):391-414 available at http://www.mdpi.com/1424-8220/12/1/391/pdf

[8] A. Bagula, G. Inggs, S. Scott and M. Zennaro, *Community Sensor Networks: An Application to Pollution Maps*, in Proceedings of the International Wireless Communication and Information Conference, Berlin-Germany, ISBN: 978-3-940317-81-0, October 2010.

[9] M. Nkoloma, M. Zennaro and A. Bagula, *SM2: Solar Monitoring System in Malawi*, in Proceedings of ITU Kaleidoscope 2011, South Africa.

[10] M. Muthoni and A. Bagula, *A Framework for Integrating Indigenous Knowledge With Wireless Sensors in Predicting Droughts in Africa* in Proceedings of Indigenous Knowledge Technology Conference 2011 (IKTC2011), 2-4 November 2011, Windhoek, Namibia.

[11] M. Muthoni, W. James and A. Bagula, *Using NLIDB to Make Weather Information Relevant to Kenyan Farmers* in Proceedings of the 2011 African Conference on Software Engineering and Applied Computing, Cape Town/South Africa, September 19-23, 2011.

[12] Intelligent Monitoring System (iMoSyS), http://www.imo-sys.com

[13] Lilongwe Water Board, http://www.lwb.mw/