Wireless Sensor Networks: a great opportunity for researchers in Developing Countries

Marco Zennaro, Bjorn Pehrson
Royal Institute of Technology - KTHSE-100 44
Stockholm
Sweden
mzennaro@ictp.it, bpehrson@kth.se

Antoine Bagula
University of Cape Town
18 University Avenue
South Africa
bagula@cs.uct.ac.za

***Abstract*— We advocate the use of wireless sensor networks in Developing Countries as we foresee they have a great role to play not only to expedite novel solutions that help mitigate development problems, but also to facilitate research activities in crucial scientific areas such as environmental monitoring, physics of complex systems and energy management. Thus we argue that there is a need for technology research and application development in the area of Wireless Sensor Networks for Development: WSN4D.**

Wireless Sensor Networks, ICT4D, science development, Africa, Developing Countries

I. Introduction

A US National Research Council report, titled: "Embedded Everywhere" [1], notes that the use of wireless sensor networks (WSN) "could well dwarf previous milestones in the information revolution". These networks provide a bridge between the physical world and the virtual world of information technology. They promise unprecedented abilities to observe and understand large-scale, real-world phenomena at a fine spatial-temporal resolution. This is so be-cause one deploys sensor nodes in large numbers directly in the field, where the experiments take place. The April 2007 issue of the Economist has a cover story entitled "When Everything Connects". The article predicts that in the coming years, invisible computing and communication power will increasingly become embedded in everyday objects.

II. Wireless sensor networks

A Wireless Sensor Network (WSN) is a self-configuring network of small sensor nodes (so-called motes) communicating among them using radio signals, and deployed in quantity to sense the physical world.

Sensor nodes are essentially small computers with extremely basic functionality. They consist of a processing unit with limited computational power and a limited memory, a radio communication device, a power source and one or more sensors, as represented in Fig.1.

Following is a short description of each component:

• Processing Unit and Memory: the task of this unit is to process locally sensed information and information sensed by other devices. At present the processors are limited in terms of computational power, but given Moore's law, future devices will come in smaller sizes, will be more powerful and consume less energy. Memory is used to store both programs (instructions executed by the processor) and data (raw and processed sensor measurements).

• Radio communication: WSN devices include low-rate, short-range radios. Typical rates are 10-100 kbps, and the range is less than 100 meters. Radio communication is often the most power-intensive operation, so the radio must incorporate energy-efficient techniques.

• Power: devices are meant to be deployed in various environments, including remote and hostile regions; consequently, they must use little power. Sensor nodes typically have little energy storage, so networking protocols must emphasize power conservation. They also must have built-in mechanisms that allow the end user the option of prolonging network lifetime at the cost of lower throughput. Sensor nodes may be equipped with effective power salvaging methods, such as solar cells, so they may be left unattended for months, or even years.

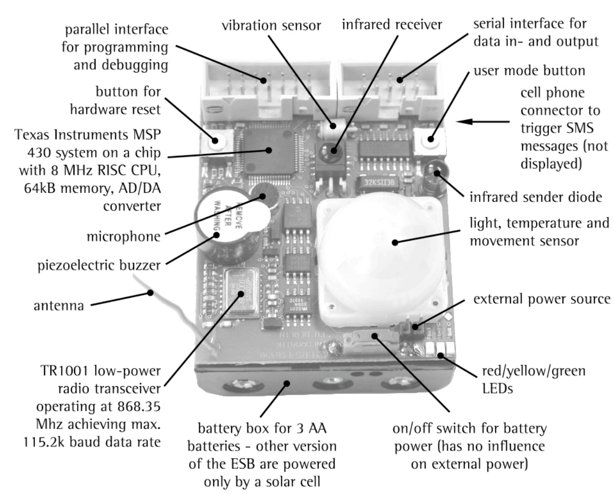

Fig1: a sample WSN node (courtesy of Dr. Haenselmann)

• Sensing device: motes may consist of many different types of sensors capable of monitoring a wide variety of physical phenomena. Common applications include the sensing of temperature, humidity, light, pressure, noise levels, acceleration, soil moisture, etc. Some applications require multi-mode sensing, so each device may have several sensors on board.

The gateway (or base station) is made of one or more distinguished elements of the WSN with some more computational, energy and communication resources. It pro-vides the interface between the nodes and the network infrastructure (the internet). A gateway must have enough computing power to be able to run a database, perform local calculation and communicate with an existing net-work (WiFi or LAN), but should be low-power enough to run autonomously in the field. The gateway is normally collocated close to more permanent infrastructure, such as at a telephone pole or on the roof of a building.

Using RFID Tags to Extend WSN Usability

Radio Frequency Identification (RFID) has developed from a next generation of bar codes technology that removes the need for active scanning into a well established technology with standardized protocols and mature commercial applications. The RFID technology identifies people and assets by using radio waves to get information on their location and status. RFID systems involves three main components: (1) a tag or transponder located on the object to be identified (2) an interrogator (reader) used to read or write/read devices and (3) an antenna that emits radio signals to activate the tag and read/write data to it.

RFID tags extend the concept of beacons used in retail stores to prevent theft into smart devices holding a unique identity of 8 bytes in length and carrying re-writable persistent storage and accessible via reader. They might be classified into active, passive or semi-active depending on whether they use their own battery to perform all operations (active), they have no battery and rely on the radio waves by a reader to power their reposes (passive) or use their own battery for some functions and the radio waves of the reader for their own transmission (semi-passive).

RFID readers use tag-reading algorithms capable of (1) identifying hundreds of tags per second (2) read data from or write to tag memory depending on permissions. They fall into two categories: (1) high frequency (HF) and ultra-high frequency (UHF) depending on the range of frequencies used, their reading range and rate, their memory size, and their power source. HF RFIDs present the advantage of low cost and use standardized frequencies (13.56 Mhz) while UHF RFIDs present the advantage of high speed (400 tags/sec compared to 50 tags/sec for LF RFIDs) and longer reading range (3-6 metres compared to 10-20cm for LF RFIDs)

A new generation of smart networks is emerging where RFID-based items are combined with sensors to form hybrid networks where smart devices such as smart cards and biometric devices are used as components of a communication network where the sensor plays the role of engine in the device's function. It is predicted that systems of such RFID tag based wireless sensor networks will add a third dimension to the first mile connectivity of future Internet to allow information to be accessed not only “anywhere and anytime” but also “using anything”.

General Applications of Wireless Sensor Networks

The integration of these tiny, ubiquitous electronic de-vices in the most diverse scenarios ensures a wide range of applications. Some of the application areas are environmental monitoring, agriculture, health and security. In a typical application, a WSN is scattered in a region where it is meant to collect data through its sensor nodes. Following is a short lit of applications of WSN.

Environmental monitoring applications of WSN include:

• Tracking the movement of animals. A large sensor network has been deployed to study the effect of micro climate factors in habitat selection of sea birds on Great Duck Island in Maine, USA [2]. Researchers placed their sensors in burrows and used heat to detect the presence of nesting birds, providing invaluable data to biological researchers. The deployment was heterogeneous in that it employed burrow nodes and weather nodes.

• Forest fire detection. Since sensor nodes can be strategically deployed in a forest, sensor nodes can relay the exact origin of the fire to the end users before the fire is spread uncontrollable [3]. Researchers from the University of California, Berkeley, demonstrated the feasibility of sensor network technology in a fire environment with their FireBug application [4].

• Flood detection. An example is the ALERT system deployed in the US. It uses sensors that detect rainfall, water level and weather conditions [5]. These sensors supply information to a centralized database system.

• Geophysical research: a group of researchers from Harvard deployed a sensor network on an active volcano in South America to monitor seismic activity and similar conditions related to volcanic eruptions [6].

Agricultural applications of WSN include precision agriculture and monitoring conditions that affect crops and livestock. Many of the problems in managing farms to maximize production while achieving environmental goals can only be solved with appropriate data. WSN can also be used in retail control, particularly in goods that require being maintained under controlled conditions – say temperature, humidity, light, etc.

An application of WSN in security is predictive maintenance. BP's Loch Rannoch project [7] developed a com-mercial system to be used in refineries. This system monitors critical rotating machinery to evaluate operation conditions and report when wear and tear is detected. Thus one can understand how a machine is wearing and perform predictive maintenance. Sensor networks can be used to detect chemical agents in the air and water. They can also help to identify the type, concentration and location of pollutants.

An example of the use of WSN in health applications is the Bi-Fi, embedded system architecture for patient monitoring in hospitals and out-patient care. It has been conceived at UCLA and is based on the SunSPOT architecture by Sun. The motes measure high-rate biological data such as neural signals, pulse oximetry and electrocardiographs. The data is then interpreted, filtered, and transmitted by the motes to enable early warnings [8].

III. ICT4D AND WIRELESS SENSOR NETWORKS

ICT4D

Information and Communication Technologies for Development (ICT4D) is the general term related to the application of Information and Communication Technologies (ICT) in development programmes in countries facing acute problems like poverty, illiteracy and a general lack of developed infrastructure. Researchers have found that ICT projects in this context have four main technological requirements in order to be successful [9]: autonomous connectivity, low-cost equipment, appropriate user interfaces and power resilience. Wireless Sensor Networks satisfy these technology requirements as explained hereafter:

• Connectivity: WSN do not depend on any pre-existing networking infrastructure. They are able to organize automatically in a mesh-type network and they are resistant to partial failures. Because the communication between devices is independent from any external network there is no cost to communicate internally. Wireless sensor networks can also be used in delay-tolerant applications, which are good solutions in countries with poor infrastructures. Data gathered by the sensors can be stored in the memory of a gateway and then transmitted when an external network becomes available. In this way no data is lost, and deployments are possible in rural environments that lack continuous or affordable network connectivity.

• Low-cost: over 100 OEMs or service providers worldwide currently offer or are developing WSN pro-ducts. Worldwide deployments are expected to grow exponentially for the next 4 years from 2.5 millions to 126 billions devices [10] and cost is expected to fall accordingly in the next years. WSN can be easily redeployed with no loss of investment and expanded when more funds become.

• Appropriate user interfaces: the data gathered from WSN are usually saved in the form of numerical data in a central base station. User interfaces are quickly being developed or already exist, to allow simple access and presentation of these large data sets [11]. Web-based interfaces allow users to monitor or control their WSN through a web browser. The product of the devices, being numerical data, can easily be synthesized into graphs, charts and spreadsheets and translated into local languages. Moreover, because the WSN devices themselves are simple, autonomous and self-configuring, they are much like appliance devices requiring little knowledge about their engineering details to be able to install, con-figure and use them. It is envisaged that these technologies will be widely adopted for specific tasks where other more general and complex technologies, such as Personal Computers, have been thwarted by the need for complex interfaces and training.

• Power: Although this is a common problem to rural/remote locations worldwide, the reality in the developing world is that access to the power grid is critically scarce and unreliable. Less than 20% of Africa's population has access to electricity and for many of them power rationing and cuts are part of the daily routine [12]. WSN can be designed so they require very little energy to operate. Sensor nodes often carry their own power sources (such as AA batteries) and may be equipped with effective power scavenging methods, such as solar cells.

Challenges

There are many challenges in implementing a WSN in Lesser Developed Countries. Power consumption is an important issue in deployments. Although for WSN nodes this is a well-addressed issue, including energy harvesting approaches, most commercial development solutions today assume that WSN gateways will encounter ideal scenarios in terms of power and connectivity when deployed. In a developing world scenario, the gateway must operate with bounded energy supplies. Since renewable energy, for ex-ample solar power, may be available at some locations, disconnected operation remains a possibility. The gateway should have sufficient solar power to store sensed data with high probabilities of service interruptions due to power loss. As for connectivity, "store and forward" seems to be an attractive alternative that requires further exploration.

Minimizing the cost of deployment is of paramount importance. Since WSN is a nascent technology, many of the existing general purposes solutions in the market are ex-pensive and/or they are not well tailored for use in the developing world. Furthermore, WSN implementations must overcome limited resources and therefore devices are often tailored to each application. As such, significant engineering efforts are normally required to fine-tune the design, a cost that most LDC institutions could not support them-selves. As a consequence of the potential for large markets for these devices however, it is expected that niche WSN devices will be developed for many uses and thus the development of a device to measure snow-melt in Alberta, might also be used to measure soil moisture in the Sahel. Moreover, because of the portability of the design, facilitated by the use of open architectures and software, these devices are expected to reach large economies of scale, far beyond what traditional measurement devices have been able to and thus the price per unit can be expected to fall dramatically.

To be usable in large numbers in developing countries, where climates are extreme and spare parts are rare, sensor nodes must also be rugged and reliable. Enclosures are needed to protect nodes from moisture and heat, but still expose sensors to the outdoor conditions that they are monitoring. As such, the environmental conditions must be taken into account when designing the system. Most systems at present are being designed for temperate climate applications and are not suitable for tropical or arid climates found in most developing countries. For example, temperature has a significant effect on the battery's effective power and the performance of the processor (CPU). In most designs, they are optimized for mid-latitude climates, where few developing countries are found.

IV. Applications of WSN in Developing Countries

Following is a review of applications of WSN in the developing world.

- The COMMON-Sense Net [13] is an ongoing project on improved water management for resource-poor farmers. A WSN has been deployed in rural Karnataka (India), and a decision support system for crop yields has been implemented. The wireless sensor network has been deployed over a small area of 2 acres to measure temperature, humidity, ambient light and barometric pres-sure. Soil moisture has been measured with a special probe connected to the motes. The first prototype of the sensor network was developed in early 2005, and has been operating in an outdoor controlled environment since April 2005. Data from the sensors are visualized through the project's website.

- A WSN had been deployed in Ethiopia to monitor anti-retroviral drug therapies for AIDS [14]. The system is expected to replace paper-based handwritten data collection systems currently used to track the progress of the disease. Ethiopia, with a population of about 70 million, faces one of the direst AIDS epidemics in all of Africa with more than 2 million thought to be infected with HIV and with about one million AIDS orphans. About 80 per-cent of Ethiopians seem to live outside it's cities in re-mote villages and doctors travel from village to village by foot or by cart. The sensors used in the project were initially developed for use in monitoring vital signs of astronauts' in space. These will now help collect information, transfer the data via wireless systems to a base station connected to the Internet and facilitate tracking of disease outbreaks, from malaria to the avian flu, within a four-hour period.

- The ZebraNet Project in Kenya [15] is an inter-disciplinary effort with thrusts in both Biology and Computer Systems. The goals are to develop, evaluate, implement, and test systems that integrate computing, wireless communication, and non-volatile storage along with global positioning systems (GPS) and other sensors. Biologists also see opportunities to use WSN to perform novel studies of animal migrations and inter-species interactions.

- A WSN to monitor water quality has been deployed in Bangladesh [16], where tens of millions of people in the Ganges Delta drink ground water that is contaminated with arsenic. A full understanding of the factors control-ling arsenic mobilization to ground water is lacking. A manual arsenic sensor, combined with the data collected from the sensor network, has been used to get a better understanding of the groundwater chemistry at shallow depths. A total of 48 sensors have been deployed in the field for a period of 10 days. UCLA scientists point out that WSN should be deployed as a shared resource, using a common model for technology adoption in developing countries. A picture of a node is represented in Figure 2.

Fig2: A sensor node installed in Bangladesh to monitor water quality (Courtesy of Nithya Ramanathan)

- Landslides are a serious geological hazard caused when masses of rock, earth and debris flow down a slope. They often occur once the soil, or rock matter on a slope reach a critical moisture level due to periods of intense rainfall and rapid snow melt, and the soil layer above its rock surface detaches and slides down the slope. Such an occurrence turned catastrophic on the 15 of December 1999 in Venezuela. Up to 30,000 people died [17]. A system called "Senslide: A Distributed Landslide Prediction System" has been developed with the support of Microsoft Research India to predict landslides in the hilly regions of western India [18]. They have implemented the design in the small on a laboratory testbed of 65 sensor nodes, and simulated results for larger systems up to 400 sensor nodes. The results are sufficiently encouraging that they intend to do a field test of the system during the monsoon season in India. Because of the low-cost of these devices this would be feasible, even for poorer nations whom have areas at risk of landslide.

- A well maintained road network is a must for the economic development and the well being of people in any country. Unfortunately, most developing countries do not have such road networks, and the lack of proper monitoring and reporting system is a contributory factor. Researchers is Sri Lanka have developed a system called BusNet to monitor road surface conditions as well as pollution [19]. Bus-Net is a sensor network that uses sensors mounted on public transport buses that cover a large geographical area. When the buses arrive at bus stations, which also function as data collection centres, gathered data are transferred over a wireless link to the collection point. Data gathered in regional collection points are transferred to buses traveling between the regional centres and the main collection centre. In this scenario the public transport system functions as a data delivery network as well as the data collection network.

- A WSN has been used for flood detection in Honduras [20], a country repeatedly hit by heavy rainfalls and devastating hurricanes in recent years. The Aguan River basin was chosen as deployment site, as it constitutes a particularly exposed area. Taking a holistic approach, the authors address the problem by subdividing the necessary actions in four tasks: event prediction, authority notification, community alert, and community evacuation. From the technology point-of-view the main issues they address are: protection of the system from environmental and human damages, appropriate coverage of the area at risk, effective prediction and electricity supply. As for coverage issues, the authors designed a two-tier architecture. 8 km radius cluster are organized as local single-hop networks in the 900MHz band. Inter-cluster communication necessitates a radio-range of up to 25 km, for which analog 144MHz radios with a custom modem were used.

- A system to monitor water quality in Malawi is under development at the Royal Institute of Technology, KTH, in Stockholm, Sweden. A student project developed a WSN to measure PH, redox and turbidity [21]. The system is going to be deployed in Blantyre, Malawi, in collaboration with local experts. Researchers of the same institute designed a low-power, low-cost, wifi-enabled gateway to be used in WSN applications in Developing Countries.

- A smart networking architecture is being developed at the University of Cape Town where enhanced functionalities are being integrated to a wireless sensor network architecture using the open SquidBee motes [22] and MySQL middleware. These functionalities include (1) optimisation to allow deployment of optimal layouts in environment monitoring and (2) situation awareness using methods borrowed from the artificial intelligence to sup-port detection and self adaptation to anomalies. The smart network architecture is intended to be used in real-life scenarios in South Africa such as

- Power monitoring: Following the country-wide power saving efforts, warnings have been issued to reduce electricity usage for both households and organizations. Experiments are being carried out using the Squid-Bee motes to sense light levels and provide warnings on higher consumptions areas in households and organizations.

- Healthcare support: The scarcity of health-care specialists in the rural areas of South Africa has raised a number of volunteering actions where doctors are flown into these areas on a temporary basis to execute different medical interventions. However, these patients re-main unattended after the passage of the medical specialists. It is believed that using tag-based wireless sensor networks will make this volunteering work more efficient by allowing remote patient monitoring under a longer period of time.

- Traffic monitoring: The town of Cape Town in South Africa has two main axes that lead to the centre where the bulk of the workforce drives from/to different suburbs every morning and evening for work. Due to poor public transportation, these two axes are usually very congested with traffic. It is expected that using the Squid-Bee motes will allow traffic monitoring on the two axes by broadcasting to networks of travelers the levels of traffic congestion on the two axes and advising on the least congestion traveling option.

- Water management: Water quality is a big challenge that leads to diseases in rural and poorest areas in South Africa. By combining situation awareness using methods borrowed from the artificial intelligence field and SquidBee sensing, a prototype is being developed at the University of Cape Town to support water quality management in the poorest areas of South Africa. This prototype will be submitted to the ministry of water and forestry of South Africa for implementation.

V. WSN: A GREAT OPPORTUNITY FOR SCIENTISTS IN DEVELOPING COUNTRIES

Sensor networks are facilitating a revolution in our understanding of nature by providing observations at a fine spatial-temporal resolution. They have the potential to revolutionize science and influence social, environmental and health issues.

In many areas of applied science researchers measure easily detectable parameters and then use simple semi-empirical correlations to infer the parameter they are really interested in. These correlations are often based on very limited data, and creating sensors to measure more directly variables of interest is critical. The advent of sensor networks with tens or hundreds of nodes in which processing will be accomplished automatically will increase the resolution of scientific data by orders of magnitude. To prepare for this paradigm shift, scientists need to begin to evaluate new and developing technologies, create training programs, develop collaborations and participate in joint efforts with experts in sensor technology, communications, information management, and networking to design and implement prototype sensor networks.

A United Nations meeting on the development of science and technology in Africa, held in 1999, revealed that the African continent is home to 13% of the world's population, but accounts for only 0.36 % of the world's scientists. Africa's share in the global scientific output is around 0.3% [23]. 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 could 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 low-cost and state-of-the-art solutions.

To realize these benefits, a broad portfolio of successful deployments will be needed as a proof of concept. It is important that the portfolio of deployed WSN is appropriate to the environment being investigated and deployments 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. Test beds for systems to be deployed also should be set up. Such test beds should produce data for scientific under-standing and should help gaining experience on how new technologies work in realistic settings. Software should be developed that will enable scientists and the general public to obtain, visualize, and make use of real-time data from the deployed networks. International involvement and technology sharing should be encouraged, and collaboration in the establishment of common network infrastructure should be sought when appropriate. New partnerships need to be developed across communities involved in specific researches.

The use of WSN will also enhance educational curricula in academic institutions. The design and deployment of a WSN requires a team-based, integrative approach. Long-term data from sensor networks will be valuable for educational use, and tools and development of curricula 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 measurement of necessary magnitudes, to identify pattern recognition strategies and exploit computational resources appropriately represent engineering challenges that can be addressed in academia.

An example of a potential use of WSN in agriculture is the rain gauge. Large farms may cover several square kilometres, and they may receive rain only sporadically and only on some portions of the farm. Irrigation is expensive and water is scarce, thus it is important to know which fields require irrigation. In addition, WSN can also be used to measure corollary effects to determine the soil nutrient and mineral levels, such as by measuring the conductivity (a measure of soil salinity), for example. Such applications are ideal for WSN: the amount of data sent through the network is very low and message latency can be on the order of the minutes. Power consumption must be low enough to last an entire growing season. The WSN is capable of much more that just these measurements. The network can be fitted with a variety of chemical and biological sensors. The data received can provide information on temperature, the need for pesticides, herbicides, fertilizers, received sunshine and many other quantities.

VI. Conclusion

What makes WSN unique are not what they can do, but rather how. Because these devices can create meshes of self-configuring wireless networks, operate with little power, in inclement weather, are small and light, and most important, they are inexpensive, they can be used for a vast array of applications where present measurement systems are economically infeasible, or logistically impossible. By using open standards and software, these devices can more easily be adapted for new uses. These new uses, spawned by the inexpensive, networked and more open and thus modular nature of this new generation of measurement de-vices will allow them to reach scales of economy that will further reduce their cost and promulgate their use. Consequently, these devices are expected to soon be within the grasp of researchers in the developing world, but now the task of preparing these researchers to employ them must begin. WSN offer opportunities for researchers everywhere to now study the data of problems that exist under their own feet. To investigate issues that matter to their society and to derive solutions to problems that afflict their com-munities.

References

[1] D. Estrin et al., Embedded, Everywhere: A Research Agenda for Networked Systems of Embedded Computers, National Research Council Report, 2001.

[2] R. Szewczyk, J. Polastre, A. Mainwaring, and D. Culler., Lessons from a sensor network expedition, in 1st European Workshop on Wireless Sensor Networks (EWSN '04), Berlin, Germany, January 2004.

[3] C. Hartung, C. Seielstad, S. Holbrook and R. Han, FireWxNet: A Multi-Tiered Portable Wireless System for Monitoring Weather Conditions in Wildland Fire Environments, Fourth International Conference on Mobile Systems, Applications, and Services (MobiSys), 2006, pp. 28-41

[4] D. M. Doolin and N. Sitar., Wireless sensors for wildfire monitoring, Proceedings of SPIE Symposium on Smart Structures & Materials/ NDE 2005, San Diego, California, March 6-10, 2005.

[5] http://alert.udfcd.org, /, last visited 30-05-2008.

[6] G. Werner-Allen, J. Johnson, M. Ruiz, J. Lees, and M. Welsh. Monitoring volcanic eruptions with a wireless sensor network. In EWSN'05, Istanbul, Turkey, January 2005.

[7] In Dust We Trust, The Economist, June 12 2005

[8] B. Greenstein, A. Pesterev, C. Mar, E. Kohler, J. W. Judy, S. Farshchi, and D. Estrin. Collecting High-Rate Data Over Low- Rate Sensor Network Radios University of California, Los Angeles Center for Embedded Networked Sensing Technical Report #55, Available online

[9] E Brewer, M Demmer, Bowei W. Du, M Ho, M Kam, S Nedevschi, J Pal, Rabin Patra, S Surana, and K Fall, The case for technology in developing regions, IEEE Pervasive Computing, vol. 5, no. 2, pp. 15-23, Apr-Jun, 2006

[10] When Everything Connects, The Economist, April 26 2007

[11] M. Demirbas, K.Y. Chow, C.S. Wan., INSIGHT: Internet -Sensor Integration for Habitat Monitoring in Advanced Experimental activities on wireless networks and systems (EXPONWIRELESS) Workshop Buffalo, NY, June 2006

[12]
http://www.pwc.com/gx/eng/about/ind/gov/ifi/pdf/electricity_sector_overview_in_africa.pdf, last visited 30-05-2008.

[13] J. Panchard, S. Rao, T. Prabhakar, H. Jamadagni, and J.-P. Hubaux. COMMON-Sense Net: Improved Water Management for Resource-Poor Farmers via Sensor Networks, in International Conference on Communication and Information Technologies and Development (ICTD2006)

[14] http://www.intelesense.net/deployments/ethiopia, last visited 30-05-2008.

[15] P. Juang, H. Oki, Y. Wang, M. Martonosi, L. Peh, and D. Rubenstein, Energy-efficient computing for wildlife tracking: Design tradeoffs and early experiences with zebranet, in ASPLOS, San Jose, CA, October 2002

[16] N. Ramanathan, L. Balzano, D. Estrin, M. Hansen, T. Harmon, J. Jay, W. Kaiser, and G.S. Sukhatme. Designing Wireless Sensor Networks as a Shared Resource for Sustainable Development, in 1st International Conference on Information and Communication Technologies and Development (ICTD), May 2006

[17] http://www.semp.us/biots/biot_362.html, last visited 30-05-2008.

[18] A. Sheth, K. Tejaswi, P. Mehta, C. Parekh, R. Bansal, S. Merchant, T. Singh, U.B. Desai, C.A. Thekkath, and K. Toyama. SenSlide: a sensor network based landslide prediction system, in Proceedings of the 3rd international Conference on Embedded Networked Sensor Systems (San Diego, California, USA, November 02 - 04, 2005). SenSys '05. ACM, New York, NY, 280-281

[19] K. De Zoysa, C. Keppitiyagama, G.P. Seneviratne, and W.W. Shihan. A public transport system based sensor network for road surface condition monitoring, in Proceedings of the 2007 Workshop on Networked Systems For Developing Regions (Kyoto, Japan, August 27 - 27, 2007). NSDR '07. ACM, New York, NY, 1-6.

[20] E. Basha and D. Rus. Design of early warning flood detection systems for developing countries, In Proceedings of the Conference on Information and Communication Technologies and Development, Bangalore, India, December 2007.

[21] http://www.tslab.ssvl.kth.se/csd/projects/0726/, last visited 30-05-2008.

[22] SquidBee. “Squidbee: Open sensor mote, http://www.libelium.com”, last visited 30-05-2008

[23] B. Mve-Ondo, Afrique : la fracture scientifique / Africa : The Scientific Divide , Ed. Futuribles, 2005