Capacity building initiatives in IoT in developing countries: lessons learned and way forward

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Introduction

The Internet of Things (IoT) refers to the networked interconnection of objects in addition to traditional networked devices, as explained in Rose et al.[1]. The IoT is expanding, as the continual decrease in size, cost and energy consumption of wireless devices boosts the number of deployed wireless devices dramatically. The number of mobile objects composing the IoT will be huge: in 2020 between 12 to 50 billion devices are expected to connect with each other, a 12- to 50-fold growth from 2012[2]. Several different technologies will converge into IoT, such as RFID systems, wireless sensor and actuator networks, and personal and body area networks, each using its own access solution. As there are many developmental challenges that the IoT can address, the technology has huge potential in developing countries: food safety can be checked, water quality can be monitored, air quality can be measured, landslides can be detected and mosquitoes can be counted in cities in real time, as described in the Information Society Report[3]. Thus, with the advancement of the IoT, there is a worldwide need for technical professionals involved in developing communication and embedded systems. To boost economic conditions and to compete in the global marketplace, developing countries should invest in training IoT professionals who can develop and deploy innovative products, and services, and provide complete solutions for a wide array of applications across a diverse range of industries.

IoT and its development

According to ITU-T Recommendation Y.2060 IoT is "a global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving, interoperable information and communication technologies" [4]. Wireless sensor networks (WSN) form the backbone of IoT networks by deploying large quantities of self-configuring small nodes, also known as motes, to sense the physical world and report to a specific centre where the remote information is analyzed and processed. These tiny electronic devices can easily be integrated into our daily life to support a wide number of applications ranging from environmental, agriculture, and health care to disaster monitoring.

We have been advocating the use of IoT and WSN for development, given the wide range of potential applications that can benefit communities and at the same time help to bridge the scientific divide, as stated in Zennaro et al.[5].

From a technical point of view, IoT nodes are low-cost and low-power devices, making them ideal for applications in environments where affordability is paramount and where power is unreliable. Nodes do not require an existing infrastructure as they can auto-configure and form a network, which makes these devices an ideal solution for remote areas. They are also flexible in terms of their use of different networking technologies. As regards the user interface, researchers have been using different strategies to communicate with illiterate communities such as audio messages or blinking lights.

When considering applications that are relevant to developing countries, IoT solutions are emerging in many fields, including water quality, agriculture, air quality monitoring, animal tracking, and disease mapping, as explained in the Harnessing the Internet of Things report[6]. IoT can also benefit scientists from developing countries in bridging the so-called scientific divide. 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. Collection of empirical data has enabled advances in science and contributed to improvements in the quality of life. Until recently, especially in environmental applications, data collection has been based mainly on a limited amount of expensive equipment using wired infrastructure. Data collection was a costly and difficult task, limited to a relatively small number of fixed, sparsely distributed locations, and maintained by organizations with large budgets. As a result, the data gathered is often incomplete, especially for developing countries and remote areas. IoT could change that radically: it is a low-cost and low-power technology that does not require any pre-existing infrastructure and can be deployed in most remote regions. The vast range of sensors that can be connected to the nodes supports many different scientific applications, such as air-quality, water-quality and soil-moisture monitoring.

To realize these benefits for communities and scientists, a broad portfolio of deployments will be needed as a proof of concept. It is important that deployment of IoT networks considers both the potential scientific impact as well as the impact on local society. Wider dissemination is needed to engage a greater audience for sensor development activities.

Short in-situ IoT training activities

In this section we will discuss the lessons learned from short training in IoT organized by the Abdus Salam International Centre for Theoretical Physics (ICTP), a UNESCO Category 1 Institution[7]. The mission of the ICTP is to foster advanced studies and research in developing countries. While the name of the Centre reflects its beginnings, its activities today encompass most areas of theoretical and applied sciences, including information and communication technologies (ICT). ICTP embraces a large community of scientists worldwide. Since its creation, the Centre has received about 120 000 scientists, half of whom have come from the developing world. Visitors have represented some 180 nations and 40 international organizations. In recent years, more than 6 000 scientists visit ICTP annually to participate in its research and training activities, and to conduct their own research. Since 1996, the Telecommunications/ICT for Development Laboratory of the ICTP has established extensive training programmes on wireless communications technologies to facilitate Internet access to unconnected academic and other institutions[8].

Since 2010 ICTP has organized 26 training activities (Table 3.1), in the 20 countries highlighted in Figure 3.1.

We can categorize the training into three generations, as described below. All three categories share some common aspects:

- The global objective of the training activities was to provide awareness about the potential of this new technology.
- The specific objectives of the training were to:
  - provide participants with a better understanding of the IoT/WSN technology in general and of the related networking requirements;
  - provide participants with an appreciation for the interdisciplinary nature of IoT/WSN by presenting the wide range of potential applications while focusing on particular domain knowledge relevant to the country/region;
  - provide participants with the opportunity to develop practical skills through hands-on, team-based design activities. These skills are the same as those required by practicing engineers, namely critical thinking, teamwork, and good communication skills;
  - develop open course material and programming examples;
  - train a future generation of trainers who will be able to share the knowledge to create local expertise;
  - 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.
- The training consisted of lectures, individual or group programming of wireless sensor

Table 3.1: Training activities organized by ICTP since 2010

Host country	Training activity year(s)
Argentina	2016
Benin	2014
Colombia	2016
Costa Rica	2015
Ecuador	2014
Egypt	2015
El Salvador	2017
Ethiopia	2017
Ghana	2011
Honduras	2017
India	2011
Indonesia	2012 and 2017
Japan	2014, 2015, 2016, and 2017 for ICT4D students
Kenya	2011
Mauritius	2015
Nepal	2018
Nicaragua	2013
Rwanda	2015
South Africa	2010
Thailand	2014, 2016 and 2017

Source: Zennaro, M., Bagula, A., Nkolomoa, M., "From Training to Projects: Wireless Sensor Networks in Africa," *Proceedings of the IEEE Global Humanitarian Technology Conference (GHTC2012)* (Seattle, Washington-USA, October 21-24, 2012).

nodes, experimenting with nodes in the laboratory and in the field, as well as collective discussions and case study presentations. The experiments took about a half of the total time.

- The training lasted five days and was targeted to about 20 participants, comprising researchers, professionals and students (both undergraduate and postgraduate) from both computer science and scientific faculties. An on-line application system was used to

Figure 3.1: Sites of IoT training activities organized by ICTP

Source: Zennaro, M., Bagula, A., Nkolomoa, M., "From Training to Projects: Wireless Sensor Networks in Africa," *Proceedings of the IEEE Global Humanitarian Technology Conference (GHTC2012)* (Seattle, Washington-USA, October 21-24, 2012).

select the participants based on a competitive criterion. This resulted in highly motivated and focused group of participants.

First generation training: WSN and short distance protocols

The first generation of training activities focused on specialized WSN boards, as reported in the ICTP-IAEA-BATAN workshop[9]. This was the time of expensive devices that worked with operating systems designed for WSN (such as TinyOS, and Contiki). The setup of the programming environment was difficult and required fine-tuning. These devices used the 2.4 GHz wireless band and had a limited range. There are few applications where such a limited range (100m maximum) can be useful, and this is particularly the case for developing countries. At that time WSN did not include GSM-based nodes and the research focus was on optimizing battery duration. Emphasis was also given to middleware as the model was to store and visualize data locally. Despite these limitations, participants in the first training activities developed interesting prototypes and new ideas, as described in Mafuta et al.[10].

Lessons learned from the first-generation training included:

- the limited range of the wireless transmission is not useful in the case of developing countries;
- middleware requires an extra piece of equipment (a PC generally) that needs to be installed and maintained;
- specialized WSN devices require a special set of skills that cannot be used anywhere else.

Second generation: open hardware and software

The second generation of training activities focused on open hardware and software devices, as briefly described by Bagula et al.[11]. This was the time of the Arduino revolution, which promised low-cost and open source solutions. By buying additional modules, one could develop useful applications. While these families of boards were cheap and well documented, they were not designed for WSN/IoT but rather for electronic prototyping. They lacked the low-power features required in developing countries. From a pedagogical point of view, they had the advantage of being very well documented in many languages.

Lessons learned from the second-generation training included:

- openness is not always the most important parameter;
- low-power is paramount for applications in areas where power supply is unstable;
- availability of documentation is a great advantage as participants can gather more information than provided during the training activity.

Third generation: rapid prototyping and data analytics

The third generation of training activities focuses on re-usable programming knowledge, on lower frequency radios and on cloud services. With the advent of microPython-based nodes, as explained in the microPython.org website, we are now able to use the same skills for programming the nodes and for analyzing data from the IoT network[12]. This makes a great difference in terms of re-usable skills. New wireless protocols in the sub-GHz bands enable long-distance applications that are particularly useful in developing countries. Finally, with the improvement of network connectivity in many countries, cloud services are being used in the training, thus lowering the initial investment barrier when deploying a complete IoT solution.

Lessons learned from the third-generation training included:

- it is advantageous to use general purpose programming languages (such as Python) that can be re-used in other contexts after the workshop;
- practical learning outcomes will be achieved through selecting equipment in the sub-GHz bands;

- policy and regulations are important when using the industrial, scientific, and medical (ISM) radiospectrum bands;

- the topics of security and privacy can now be addressed as we use "standard" programming languages and tools instead of prototyping ones;

- cloud services are a great advantage because they allow for rapid storage and visualization of the data.

Lessons learned

From the 26 training activities organized in the last eight years we learned much. Firstly, workshops should not focus on one specific application but should present the main concepts in IoT. Participants will then develop their own applications, which will differ from country to country. Secondly, regulatory issues are important if IoT networks are to be deployed outside academic environments. While radio regulations are clear (in respect to which frequencies should be used), regulations pertaining to IoT are not clear. One example is duty cycle limitations which are valid in Europe but are not defined in many African countries. Type approval is also a topic to be presented, as participants will seek to order equipment after the training activities. Finally, production of written material is useful as many participants act as trainers and want to reproduce the workshop in their own institution. A handbook/guide developed in a modular way would certainly be utilized.

Training needs identified and proposed solutions

The main training need is related to the multidisciplinary nature of IoT. It is challenging to present IoT in a short training course as the required background knowledge is very wide, ranging from wireless concepts to network protocols, from programming to databases, and from data science to sensor electronics. Electrical engineers lack the programming knowledge, while computer scientists lack the basic radiofrequency (RF) engineering concepts. We found a solution in using Python-based IoT nodes. By learning Python (the second most used programming language in the world, with many online courses and freely available resources), participants can program the IoT nodes, manage the database and analyze the data. We can therefore focus on RF concepts without devoting too much time to presenting different programming languages/ environments. Another advantage of using a high-level programming language is that participants can start prototyping their application on the first day of the workshops. This gives them time to make improvements during the week and to make modifications based on lessons from the lecture classes.

Long Term training at the African Centre of Excellence in Internet of Things (ACEIoT) in Rwanda.

Although universities in the developing countries have contributed significantly to reducing the human capital gap in the field of science and technology, their much needed contribution to the relevant science, technology and innovation (STI) degree programmes, focusing on hands-on skills to accelerate economic transformation and competitiveness, has been limited. For developing countries, ICT investment is an essential driver for economic development. With the advancement of the IoT, intelligent products that operate and exchange information efficiently have created a worldwide need for technical professionals involved in developing communication and embedded systems. To boost economic conditions and to compete in the global marketplace, developing countries should invest in training IoT professionals who can develop and deploy innovative products and services, and provide complete solutions for a wide array of applications across a diverse range of industries.

Consistent with these requirements, the University of Rwanda - College of Science and Technology was selected to establish an African Centre of Excellence in IoT (ACEIoT) by the World Bank's ACE II project. The Centre is aimed at Masters and PhD training in the field of IoT, bringing together researchers and practitioners whose work will have an impact on the development of IoT-driven service provisioning solutions for a developing nation like Rwanda, and for Africa as a whole.

Although much progress has been made in the field of IoT by developed nations, the developing countries are lagging due to the lack of skilled people. There is huge demand for WSN and embedded systems professionals. Embedded computing systems are now pervasive and ubiquitous. They are found in personal digital assistants (including smart phones), biomedical devices, networked sensors, mobile robotics, automotive and airlines systems, smart cards and RFID tags amongst others. The IoT market is driven by tomorrow's digital cities, Industry 4.0 and cyber-physical systems (CPS). As modern systems are yet to be deployed in many industries, millions of new jobs are forecasted in this field in the near future.

PhD and Masters Programmes offered at ACEIoT

In order to address the skill gaps, ACEIoT offers PhD programmes in two specializations: PhD in Wireless Sensor Networks (WSN), and PhD in Embedded Computing Systems, and two Masters programmes: MSc in IoT - Wireless Intelligent Sensor Networking (WISeNet) and MSc in IoT - Embedded Computing Systems (ECS). These graduate programmes and the other capacity building interventions of ACEIoT are clearly aimed at addressing the skills priorities of the region, so that graduates from ACEIoT may fill the ICT skills gap of the region. All students of the Centre will undertake market-oriented, demand-driven, and problem-solving research for their project/dissertation work. Skills learned by the students will be directly applicable to the needs of the various sectors, including smart meters for the energy sector; precision agriculture for the agricultural sector; smart wearable health monitoring devices for the health sector; and even early warning systems where different sensors are developed for detection and timely alert of various disasters including landslides, and potential volcanic eruptions. Students will be trained to acquire sufficient entrepreneurial skills to become job creators rather than job seekers. Projects can be simulation-based or experimental but are expected to demonstrate innovations or solutions suitable for local needs.

Real life examples of IoT application

Embedded devices, such as sensors, are used to monitor the use of renewable energy sources, such as photovoltaic. As this is the only available technology to provide access to electricity in many regions, it is possible to use these devices to monitor the state of batteries, the usage of energy during the day and the status of the panels. Thus, embedded devices drastically reduce the cost of human transportation to measure such parameters. Moreover, sensors are integrated into all forms of energy consuming household devices (such as switches, power outlets, bulbs and televisions) and can communicate real-time data to the utility supply company so that power generation and energy usage may be balanced effectively.

Many global companies from the developed world are already investing in the African market with products for the energy sector, and drones for various applications, but they are generally very expensive. The human capital trained through degree programmes at ACEIoT should develop products and services for the local market which are both cost effective and easily deployable.

Another example of a real use scenario is from the health sector. Most rural and remote health centres in sub-Saharan African countries are still facing a critical shortage of nurses and doctors. This deficit is often manifested in long queues of patients in waiting rooms over many hours. Traditionally, health centres apply a first-come-first-served (FCFS) rule to schedule patient consultations with the limited pool of healthcare specialists (doctors or nurses) without considering the severity of each individual patient's health condition. This is not an efficient use of scarce healthcare resources. To solve the problem the ACEIoT is planning to design a smart vital signs acquisition chair (integrating various embedded bio sensors) that enables prioritization in the scheduling of queuing patients by assessing the health condition of a patient. This is estimated using the measurement of vital signs, together with the waiting time and distance between the centre and the patient's home. The proposed system may also be upgraded to provide queuing information at a given health centre, either by SMS or Internet, so that patients can schedule a health centre visit by considering the likely wait time at the target centre.

Drones or Unmanned Aerial Vehicles (UAVs) technology is another emerging and rapidly evolving technology. There are many innovative applications of drones for the African region. In Rwanda and Tanzania drones are used by Zipline to transport blood to remote areas and to deliver essential medical supplies. Livestock farmers will also benefit from livestock vaccines delivered on the farms to control outbreaks of disease.

Drones also have an impact on the agricultural sector. In countries with hilly terrain, such as Rwanda, farming takes place on steep slopes and sometimes it is very difficult to reach some of the areas. The use of modern technology such as drones can improve farming and crop production. Applications include seed sowing, smart irrigation and soil analysis. Various types of embedded devices such as sensors and other devices will be integrated to the standard drone structure, which can provide live data from a range of sensors, collect soil samples and undertake agricultural surveys. Kenya is using drones to end the Rhino poaching crisis, while Zanzibar uses drones for geo-spatial mapping of Zanzibar islands.

The design of sensor systems for drones is an important application of WSN and ECS, requiring dedicated electronics for signal acquisition and amplification. By means of digital signal processing, measurement information can be extracted and transmitted. Decisions about hardware and software realization of system functionality requires experts educated in both fields. The ACEIoT graduate programmes will equip the students with the necessary skills in the design and development of embedded devices, like sensors and other devices, and in the integration of these to the basic drone structure for various drone applications.

The above real-life examples represent only a small subset of the possibilities offered by IoT for solving developmental challenges. As the ACEIoT is a regional centre of excellence, the partners of the consortium and the region will identify many more challenges where IoT could play a role in providing innovative solutions.

The World Bank funding for the ACEIoT supports the procurement of required cutting-edge research equipment for the wireless sensing laboratories and ECS laboratories, and the upgrading of research facilities for the efficient delivery of the PhD and Masters programmes. This will also encourage international collaborators to conduct studies at the Centre.

ACEIoT's partnerships with regional and international universities and research institutions will enable collaborative research studies of relevance to global, regional and national development needs in the IoT application domain. Technical papers describing original ideas, ground-breaking results, and/or real-world experiences involving innovative IoT applications can be published in widely respected journals, thus improving the ranking of the partnering universities and improving the University of Rwanda's world ranking.

Conclusion and next steps

The promise of IoT is connecting billions of devices for multiple uses as we have seen in the above sections. It is believed that a large quantity of low-cost sensors with long battery life will allow much more data to be collected and more insights to be gathered from big data, which can help the government and people of developing countries to become globally competitive. As the economics of IoT changes, IoT sensors will become inexpensive (less than a few dollars), and micro-controllers and edge computing will reduce in price. RF communication and the scalability of IoT will enable millions of sensors to be deployed in a country, facilitating big data analytics and AI, Machine Learning, new business models and application programming interfaces (APIs) – all created from simple payloads of data from the sensors. Therefore, the key task for trained professionals undertaking short- and long-term training is to examine possible uses of the technology and/or develop or deploy solutions.

We presented our experience in training participants from developing countries in IoT. While the short workshops can ignite interest in this new technology, a complete academic course will create the foundation for future success with a new generation of experts. The main lesson is that IoT will succeed when the deployment of technology is generated by country needs. There is also a need for coordination of vertical applications that can fulfill the needs of developing countries, and ITU can certainly play a role in this. Given ITU-D's role in fostering capacity building initiatives and in supporting sustainable ICT initiatives, a virtual environment could be created for the exchange of lessons learned in IoT4D projects.

Endnotes

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