IoT Applications that work for the African Continent: Innovation or Adoption?

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***Abstract*—The realisation of the Internet of Things is driven by several enabling technologies needed for identification, sensing and communication. These include the Internet itself, Radio Frequency Identifiers and wireless sensor networks. Africa has not kept pace with technology advancements; the Continent continues to contend for the last position in virtually all technology spheres. In the Information and Communications Technology sector for instance, Africa has only 7% of her households on the Internet; this is far behind the world's figure of 41%. However, all is not that dim; there is some evidence that the Continent can be on forefront to some technology advancements. As the world's researchers and businesses rush to unfold Internet of Things, it would be valuable to pose the question; "given Africa's pronounced lag in the baseline technology needed to implement Internet of Things, should the Continent go for adoption or innovation?" By choosing innovation at this early stage of the developments in the Internet of Things, the author argues that Africa will avoid the famous problem of "transferring of Northern designs to Southern realities". Taking the case of a drought early warning and assets tracking systems, the author demonstrates that by innovatively incorporating the realities such as the prevalence of African indigenous knowledge on weather, unreliable communication, low-end mobile phone handsets, among others, a home-grown Internet of Things flavour has higher chance of succeeding.

Keywords—Internet of Things; Technology Innovation; Technology Adoption; Drought Early Warning System; Wireless Sensor Networks; tracking and monitoring system

I. INTRODUCTION

Internet of Things (IoT) is currently one of the most vigorously pursued research topics in the computer-internetworking realm. There are a couple of definitions and visions of IoT; the most common vision being "anywhere, anytime, by anyone and anything" (the "4A vision") while the most common definition is: "a network of interconnected things/objects that are uniquely addressable" ([1] and [2]). The realization of the ideal vision of IoT is to be found in embedding computation capability in every kind of object and living thing. This includes the inherently networkable objects such as computers, mobile phones and Radio Frequency Identifier (RFID) tags as well as new entrants into the world of networks such as everyday objects/things like our clothing and food as well as living organisms such as wildlife, livestock and plants. Wireless sensor networks (WSNs) are an invaluable component of realizing IoT; they form the 'digital skin' through which to 'sense' and collect the context of the surroundings and information of the physical environment. WSNs are especially instrumental in introducing intelligence to IoT because of their ability to cooperate and collaborate in carrying out tasks.

Despite the fact that RFID technology has been very successful in the broad array of its application areas, it is mostly used to identify objects and/or to track their location without providing any indication about their physical condition. On the other hand, WSNs are collections of millimetre-scale, self-contained, micro-electro-mechanical devices that contain sensors, computational-processing ability, wireless receiver and transmitter technology and a power supply[3]. There exist a range of sensors capable of sensing physical, chemical and biological properties of objects and their environment. On their own, most WSNs applications have been confined within the research/academic world. Further, the cost of sensor boards is still prohibitive; boards cost between 100 to 800 Euros[4]. The wireless sensors communication protocols only allow coverage of between 100 and 300 metres. The Global System for Mobile Communications (GSM) in most African countries is not reliable enough to support interruption-free communication[5]. Integrating WSNs, RFIDs mobile phones and other technologies prevalent in Africa therefore introduces scalability, portability, cost-effectiveness, reliability and intelligent monitoring/detection abilities to applications.

Implementation of weather and climate change monitoring systems in many Sub-Saharan Africa (SSA) countries is hampered by among other things, inadequate coverage by weather stations. Ideally, when deployed in their hundreds, WSNs-based weather meters can mitigate this by capturing weather parameters at micro-level. Even then, with a functioning WSNs-based drought monitoring system, there is no guarantee that the people (especially the small-scale farmers) that need it most in SSA will utilise the information for an array of reasons that are documented in literature[5]. For example, studies reveal that over 80% of farmers in some parts of Ethiopia, Kenya, Zambia and Zimbabwe relied on Indigenous Knowledge Forecasts (IKFs)[6]. This is where Internet of Things (IoT) comes in; instead of creating a homogenous drought forecasting system made up of sensors, a system made up of heterogeneous weather information sources (such as sensors, mobile phones, conventional weather stations, indigenous drought forecasters (rainmakers), mobile phones, smart billboards and so on) would suffice.

Like other technological innovations, there is negligible efforts towards implementing/designing IoT in Africa and the Continent is waiting for the bigger brothers(Europe, North America and Asia) to innovate then she adopts. The argument here is that Africa does not have to follow this old trend that has always led to solutions that do not fit the realities in the Content as supported by the famous; "transferring of Northern designs to Southern realities"[7].

II. Background Literature

A. Current Implementations of IoT

As with most other technologies, the noticeable IoT projects are headed by multinationals such as IBM's Smatter Planet Project[8] and HP Labs' Central Nervous System for the Earth (CeNSE) project[9] and research consortiums like the European Research Cluster on the Internet of Things[10]. The second observation is that none of these initiatives are directly based in or involving Africa let alone African researchers-driven. The only indirect planned involvement (of the Continent) known to the author is through Pursuing ROadmaps and BEnchmarks for the Internet of Things (PROBE-IT). The latter is a sub-project under The European Research Cluster on the Internet of Things (IERC) whose aim is to support exploitation of European research advances in IoT deployments. Given that there no known documented IoT deployments in Africa as yet, this involvement may as well be futile. There are tens of experimental business ideas around IoT out there; some of these that were lined up for showcasing in the Internet of Things 2013 [11] included Good Night Lamp™, Xively Cloud Services™ and BERG Cloud.

B. IoT for Africa – Challenges and Opportunies

1) Challenges

According to the United Nations Development's Programme (UNDP) Human Development Report of 2013 [12], Africa contributes 35 of the 45 poorest countries. Given these high poverty levels, most African governments (especially the Sub-Saharan Africa) are still struggling to provide basic needs (such as food, shelter, health, water and sanitation and education among others) and therefore technology innovations take a back seat. While the world's Development Index stands at 0.694, the Sub-Saharan Africa's one is at 0.475.

The frequency, magnitude and duration of natural disasters triggered by climate variations are on the rise globally, thanks to events such as climate change, global warming and population growth. Droughts continue to affect millions of people in Africa; According to the World Disasters Report of 2013 (https://www.ifrc.org/PageFiles/134658/WDR%20**2013**%20complete.pdf), Africa contributed 56% of droughts that occurred between 2003 and 2012; they affected 26% of her population. Most of these occurred in the Sub-Saharan Africa (SSA) [13]. The uniqueness of the problem in SSA however, is to be found in the inadequacy and ineffectiveness of the Region's preparedness to these disasters([5] and [14] . Further, most economies in SSA are driven by the notoriously climate-sensitive agriculture sector and as Virji et al.[15] put it: "...agricultural production and weather are so highly interrelated that a good rainy season means a healthy economy, and failure of the rains … means famine and death" (pg 8). Further: "Of the ten countries with the highest levels of hunger, and of the ten whose scores have actually increased since 1990, nine are in Sub-Saharan Africa in both cases"[16].

In terms of Information and Communications Technology indictors, while 41% of the world's household have access to the Internet, Africa is lagging far behind at 7%. Secondly, Africa has abysmal penetration rate for landline telephone, the number of fixed-broadband subscriptions in Sub-Saharan Africa stands at a miserable less than 1% compared to 27.2% in developed countries. This mostly is due to high cost of subscription which is currently higher than 30.1% of average monthly incomes. Moreover, only 10% of this fixed-broadband (of < 1% in Africa) offers speeds of at least 2 Mbit/s [17].

2) Opportunities

Africa's mobile-cellular penetration is higher than 63% and although this is still the lowest, the Continent brags of having the highest mobile-cellular subscription rate of over 6%. Further, although still lower than in the developed countries, mobile broadband costs less than half of fixed broadband in Africa. This explains why African countries are leapfrogging Internet connectivity using mobile phones; rather than first building a landline infrastructure and then moving on to mobile, Africa is jumping straight to mobile. Innovative applications in all spheres of life have converted mobile phones in Africa into Automatic Teller Machines (ATMs), landlines, agricultural extension officers, clinical officers, mathematics tutor and so on. A more interesting and unique cultural aspect to mobile usage in Africa is that of one-phone-many-users. This makes it possible to have phone access levels that are much higher than the cell-phone penetration levels. This art of sharing is being leveraged to create successful mobile solutions to problems facing communities in Africa.

Advancement in mobile phone technology has resulted in phones that can ably compete with personal computers of less than a decade ago; the devices (especially smart phones) are no longer used as mere phones for making/receiving calls. Mobile phones have become critical tools for accessing the Internet and are therefore bound to play a critical role in the implementation of IoT in Africa. A survey conducted in 2013 in the 3 major cities in South Africa (Johannesburg, Cape Town and Durban) revealed that 46% of surveyed township residents use their mobiles for browsing the Internet and 43% for accessing Facebook [18]. Integrating mobile phones with/into IoT brings several advantages: first, the phones have highly developed user interfaces and can be used as both input and output devices for IoT. This could take the form of text messages, audio, video, text to speech capabilities and so on. The phones' network interfaces to cellular networks could be exploited to connect to the Internet and reach remote people and objects (the things in IoT) over channels such as Short Messaging Service (SMS), Multimedia Messaging Service (MMS), General Packet Radio Service (GPRS), Bluetooth, and WiFi among others

The other opportunity that can be used to make IoT succeed is the proliferation of start-up incubators and innovation hubs in Africa. Examples include, *iHub* in Kenya (www.ihub.co.k), *mLab* in South Africa (www.mlab.co.za) and *mFriday* in Ghana (www.mfriday.org)designations).

3) Innovation versus Adoption

In the Collins English Dictionary, innovation is defined as "something newly introduced, such as a new method or device". A casual definition of technology innovation would therefore be "new technology introduced/created". Technology adoption (and or diffusion) is a widely researched area and it is not the intention of the author to pursue this in details in this paper. It means "... the first use or acceptance of a new technology or new product" [19]. It is indeed true that technology innovation should be followed by technology adoption/adaptation otherwise the efforts of the innovation become futile. The gist of this work is a simple one; African countries should not simply import the IoT technology from the west and adopt/adapt it; they should rather create (innovate) their own relevant technology. The innovation route is preferred because IoT has great potential solving many unique problems facing Africa especially in the area of environment, weather, climate change, agriculture, health and security. As expounded above, Africa has very unique challenges and opportunities and only home-grown solutions built by or in consultation with the Continent (Africa) will succeed.

III. ROADMAP FOR IMPLEMENTING IOT IN AFRICA

As explained in sections above, Africa presents unique opportunities and challenges and IoT solutions must therefore incorporate some implicit elements of cultural transfers and mutual learning. This is more so for application-specific issues and it is the author thesis that Africa must go for innovation in this regard. However, the baseline challenges of IoT such as standardisation, security and integration of the 'things' remain universal and open-innovation (leveraging with works of other researchers elsewhere in the world) should be considered. To this end, the author, in collaboration with researchers from three universities (2 in South Africa and 1 in Kenya) initiated 2 IoT projects in the areas of drought prediction and tracking. These are currently being run in parallel with a project aimed at creating a generic integration framework for the IoT 'things'.

A. Generic IoT Integration Architecture

As shown in figure 1, the generic architecture assumes existence of generic Information Generators that form the 'things' such as sensors, mobile phones, RFID tags, plants and people. The Information Generators (Layer 1) must be internetworked (Layer 2) in some way in order to enable them collaborate, collect and collate whatever data items involved in the application(s). This data is then handed over to an application specific layer; Information/Data Integration (Layer 3). For instance, in a drought prediction application, data from weather sensors, weather stations and mobile phones would be integrated before being fed to a drought prediction module. Another application dependent layer, 'Information Wrapper' (Layer 4) is used to format the output of the application into various formats for each consumer type. For instance, information to be designated via text messages would be different from one to be disseminated via web pages and audio announcements and so on. The implementation of these layers is governed by the three components of the Service Oriented Architecture (SOA); service description, service advertisement and service composition respectively[20].

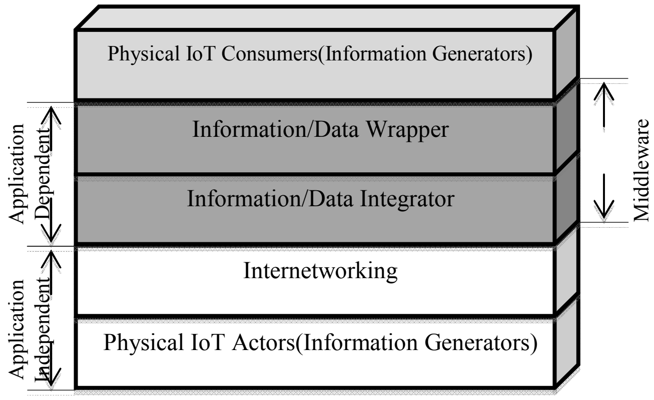

Fig. 1. Proposed Generic IoT integration Architecture

B. Drougth Early Warning System – IoT Application

Information is power and ensuring that the local communities have access to tailor-made information on impending droughts is one way of giving them power to protect themselves from their negative effects. Despite the challenging contexts they operate in, meteorological institutions in Sub-Saharan Africa (SSA) continue to provide regular climate forecasts especially in form of Seasonal Climate Forecasts (SCFs). However, the utilisation of this information by the small-scale farmers whose crops/livestock depend solely on rainfall is still below par [21]. Studies [[6] and [22]) reveal that over 80% of farmers in some parts of Ethiopia, Kenya, Zambia and Zimbabwe relied on IKFs. However, IKFs are currently facing challenges from various quarters especially from climate change, urbanisation and population growth.

There are renewed efforts towards promoting IKFs especially on disaster management and how to integrate them to the SCFs ([5], [21], [23], [24] and [25]). This is driven by the realisation that SCFs and IKFs complement each other and that the rich IKFs could help in making the forecasts more relevant to the local people's context. Though having generated promising results, such integration initiatives still face the challenges of scaling up beyond small communities/villages and scaling down in terms of availing localised weather data. Innovative use of the readily available mobile phones and the versatile wireless sensor networks technology can be used to address these two challenges and hence accelerate these success stories. In doing so, IoT could be used to create a system made up of heterogeneous weather information sources (such as sensors, mobile phones, conventional weather stations, indigenous drought forecasters (rainmakers), mobile phones, smart billboards and so on).

A system prototype for predicting drought composed of the several components as shown in figure 2 was developed to evaluate the IoT architecture shown in Figure 1.

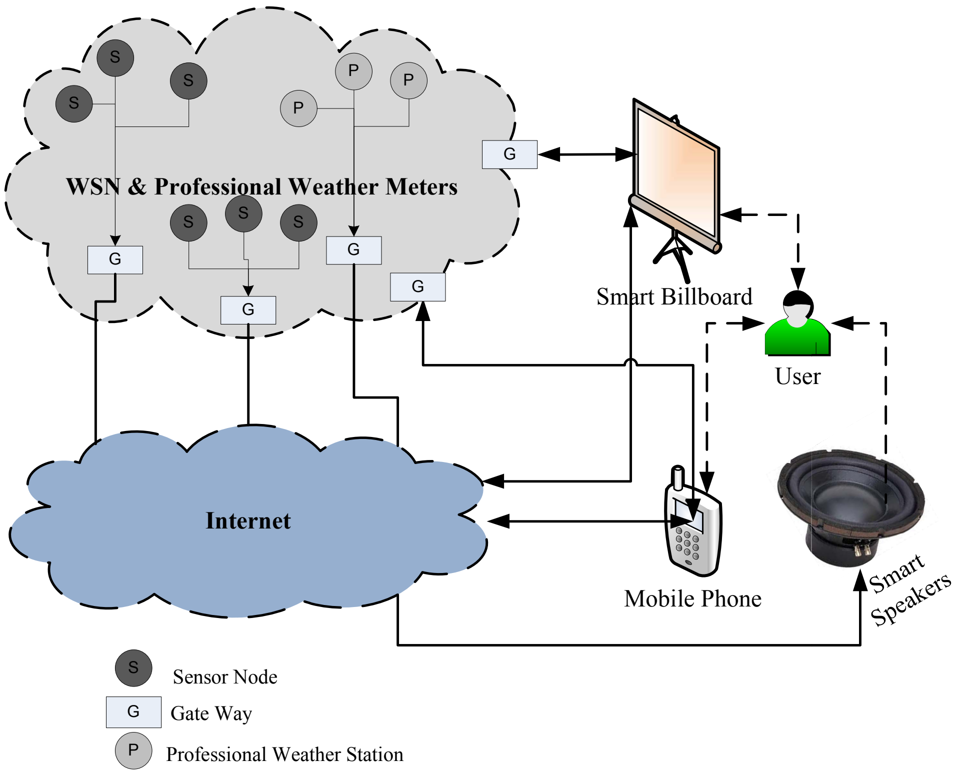

Fig. 2. Components of the DEWS System Prototype

C. Innovative Implementation of IoT: Case of Assets Tracking System

Insecurity, both of our assets and lives is everywhere. In a recent news item in the South Africa's local media, a mother was mourning her daughter who died while working in the underground of one of the mines. Back in the office, a colleague narrates the agony of a commercial farmer whose entire herd of cattle was stolen, taking away not only his lifetime savings but also that of his parents and grandparents. As a matter of fact, in the 2008/09 financial year, South Africa lost about 34 000 cattle, 60 000 sheep and 28 000 goats to stock theft, amounting to a total of R366 million. Statistics from other parts of Africa are not any different. For instance, hundreds of innocent lives have been lost over the years among the nomadic communities in Ethiopia, Kenya, Somalia and Uganda due to cattle rustling. Wireless sensor networks (WSNs), if innovatively integrated with the more mature Radio Frequency Identifier (RFID) technology and the relatively prevalent mobile phones is able to deliver an effective and affordable tracking solution that can address the many insecurities facing our communities today.

1) System Architecture

In order to ensure that the system is generic (can be ported across domains), architecture made up of the following four layers as shown in figure 3.

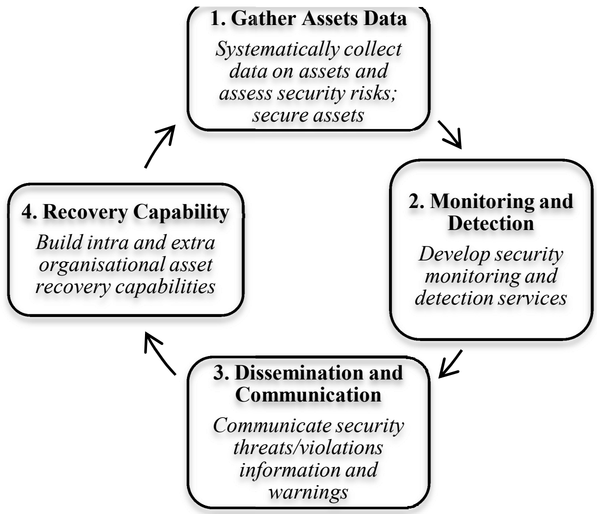

Fig. 3. Asset Tracking System Architecture (adapted from [26])

(a) **Gather Assets Data**

The aim here is to maintain up to date record of all assets and answer questions such as what, where, who, when, why and how. Some of the main operations include ability to:

- Register assets; store the details in a database
- Assign, re-assign, transfer or withdraw assets to staff members

- Authorize movement/exit of assets from the institution premises; the staff member currently assigned to the asset could do this via an SMS or biometric reader. Appropriate status (out) is updated in the database

(b) **Monitoring and Detection**

This is the main function of the system; it is made up of autonomous, intelligent, configurable and robust (especially redundancy to take care of failure of components) ways of automatically detecting assets' security violations. It in particular detects unauthorized exit of an asset. Here, a combination of RFID readers, RFID tags, wireless sensor networks, mobile phones, GPS devices, alarm bells and biometric readers/scanners are used.

(c) **Dissemination and Communication**

This module is responsible for sending appropriate alerts/information relating to assets' security violations to all stakeholders. It includes alarms at the institution's main gates, SMS to staff members assigned to the particular asset and a whole chain of people in charge assets at the institution. IoT paradigm plays a critical role here as well as in module (c) above.

(d) **Recovery Capability**

This module handles some of the activities needed to recover or deter further movement/usage of a lost asset. Though most of such activities may not be automated, this module incorporates measures such as:

- Activation of GPS(where present) reader on the device to enable tacking its movement
- Activate inbuilt camera (where present) and enable streaming of images from the device to the system
- Deactivate critical components of the asset (e.g. erase the hard disk of a laptop and deactivate the keypad of a cell phone) to avoid access of critical company information in a lost asset.

IV. CONCLUSION AND WAY FORWARD

In this paper, the need for Africa's participation in the IoT innovations has been presented. This has been done by presenting relevant challenges and opportunities that justify African-approaches to IoT. A brief description of two applications of IoT in the area of drought early warning systems for Sub-Saharan Africa that is currently under evaluation is also presented. The architecture of a second application in the area of security and tracking and that is whose prototype is currenly being tested is presented too. Both of these applications are designed with consultation with stakeholders and contextualizes the realities in Africa.

A generic service-oriented architecture for integrating IoT 'things' has been introduced. This is currently under development and some aspects of it were applied in developing the drought early warning system prototype. The complete implementation of this architecture will precede the realization of the tracking system to ensure that the resulting system is portable across problem domains such as security in South African underground mines, tracking activities in the Kenya's hydroelectricity and geothermal power plants. It is therefore true that the work presented here is 'work in progress' and a lot more need to be done before the announcement of results can take place.

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