

Enabling The Internet of Things in Developing Countries: Opportunities and Challenges

Md Nazmus Sakib Miazi*, Zenville Erasmus[‡], Md. Abdur Razzaque*, Marco Zennaro[†] and Antoine Bagula[‡]

* Department of Computer Science and Engineering, University of Dhaka, Bangladesh.

[†] Wireless Laboratory, International Center for Theoretical Physics (ICTP), Italy.

[‡] Department of Computer Science, University of the Western Cape, South Africa.

Email: sakibnm@gmail.com, zerasmus@uwc.ac.za, razzaque@du.ac.bd, mzennaro@ictp.it, bbagula@uwc.ac.za

Abstract—This paper presents an overview of the enablement of IoT in developing countries and discusses the visions, general applications, opportunities and challenges of IoT in these countries. It also touches on issues relating to security, privacy, trust and the accompanied complexity. The potential applications for IoT are countless and can optimize processes with a direct impact on society. Certain challenges have to be addressed to make IoT deployment successful. It will be shown that some of the challenges can be turned into opportunities and that IoT has good chances to succeed in developing countries.

I. INTRODUCTION

The *Internet of Things (IoT)* is a novel paradigm that is rapidly gaining ground in the era of modern pervasive computing. The concept is basically developed on an idea, where there are numerous *things or objects* - such as Radio-Frequency Identification (RFID) tags, sensors, actuators, mobile phones, etc. - that are connected with the Internet. Each of the objects has a unique address and is able to interact with other objects. The *things or objects* co-operate with each other to reach a common goal. The IoT is a triumph of distributed computing systems having a huge compatibility to compile, process and distribute information using wireless and wired communication systems.

The term Internet of Things was first coined by Kevin Ashton in 1999 in the context of supply chain management [1]. Nevertheless, in the past decade, the term IoT evolved as a keyword of modern technology covering a wide range of applications like intelligent transport, smart health care, smart utilities, etc. In summary, we can define IoT as an integrated Internet system, that is able to cope with highly dynamic global network infrastructure, having the capability of configuring themselves according to the standard communication protocols, where every single *thing* has its own identity and intelligent interfaces for seamless integration into information networks.

A. Visions of IoT

The vision of the Internet of Things is to merge computer networks, Internet of Media (IoM) and Internet of Services (IoS) with Internet of Things (IoT) for developing a global IT platform of seamless networks [2]. IoM is a system that facilitates Multimedia applications - such as multi-player games, digital cinema, virtual world simulations, etc. It addresses the challenges in video processing, 3D processing and high

demands for data rate to be adapted with network conditions. IoS is a system of delivering software based components throughout the global networks. Enterprise inter-operability, Service Web, Smart Grids and Semantic Web are the key research challenges to build up an integrated and robust IoS.

IoT demands scalability, i.e., the edge points will be connected through Clouds, not a Local Area Network (LAN). Communication challenges are to be drawn more among *things* and data-centers. The IoT needs enhanced processing power with large storage capacity having always-on connectivity. At the same time, the cost is needed to be minimized. To facilitate the end-users with the best of IoT, the applications, services, middle-wares, networks and endpoints are to be structurally defined in an entirely new way.

The IoT makes it happen between people and things to be connected to each other at Anytime, Anyplace, with Anything and Anyone, ideally using Any path/network and Any service. This inscribes objects much flexibility in terms of the 6 C's - Convergence, Content, Collections (Repositories), Computing, Communication, and Connectivity in the context where there is seamless interconnection between people and things[2].

B. General Applications of IoT

The Internet of Things denotes a plethora of *things* interconnected with each other seamlessly. We can divide the general applications of IoT into three domains, such as, Industry, Environment and Society. Activities involving financial or commercial transactions among companies, organizations and other entities reside in the Industry domain. The Environment domain consists of activities related to the safety, maintenance and development of all natural resources. And finally, the Society domain contains the initiatives referring to the development and inclusion of societies, cities, and people. These domains are not isolated ones, rather they have strong correlations that enable us to develop new applications and services exploiting intra and inter domain dynamics.

Now, we discuss a few important fields of the IoT. First of all, we can think about the Aerospace and Aviation industry, where IoT certainly helps to improve aviation safety and security. Secondly, we can look into the smart Automotive Industry, where RFID is used everywhere in automobile production. Prominent technologies like Dedicated Short Range Communication (DSRC), vehicle-to-vehicle (V2V) and vehicle-to-

infrastructure (V2I) communications, Intelligent Transportation Systems (ITS), etc. are fully being integrated with IoT to ameliorate the current status of vehicle safety services and traffic management systems. In addition, IoT is integrating GSM, Near Field Communication (NFC), low power Bluetooth, WLAN, GPS and sensor networks to develop a whole new platform for ensuring better services in the Telecommunications Industry.

The IoT has a great prospect in the Medical, Health and Pharmaceutical industries. IoT can facilitate patients with the help of intelligent monitoring technology for diseases, ad-hoc diagnosis and prompt medical service in case of accidents. Edible and biodegradable chips are being used for guided tests and treatments. In case of the Pharmaceutical industry, it is really important to maintain the safety and security of the distribution of products. In terms of IoT, tracking the supply chain with the use of intelligent systems and monitoring everything with advanced sensor networks, is certainly very beneficial to the people related to this industry.

The IoT makes the retail and supply chain management (SCM) operations smooth and flawless. For example, with RFID-equipped items and smart shelves that track the present items in real time, a retailer can optimize many applications. Research shows, 3.9% of loss happens worldwide when shelves go empty and customers do not get the desired product [3]. So, IoT can save a significant amount of money in retail stores facilitating them with smart Supply Chain Management systems. Moreover, in the Manufacturing, Processing and Transportation industry, the IoT can be a great boost-up for the integrated systems. Furthermore, IoT shows great prospects in Agriculture, Environment, Media and Entertainment industries.

C. Contributions of This Work

In this paper, we mainly focus on the prospects, challenges and the probable solutions to the problems for enabling IoT in developing countries. In developing countries, people face a lot of problems to have access to the communication technologies in terms of poverty, lack of Internet speed, low levels of expertise, and overall lack of infrastructure. The authorities face enormous challenges to improve the current systems to make the infrastructure capable of deploying IoT as a whole. We identify the opportunities of IoT in developing countries in section II. We state the challenges to exploit the opportunities for deploying IoT in developing countries in section III. We discuss the possible solutions to the challenges and provide guidelines to ameliorate the current condition to enable IoT in developing countries.

II. OPPORTUNITIES OF IOT IN DEVELOPING COUNTRIES

The prospect of IoT in developing countries is huge, ranging from agriculture to smart city applications. In this section, we discuss the opportunities of IoT for the emerging sectors in the developing countries. We anticipate the promising prospects of IoT in the fields of transportation safety, agriculture, environ-

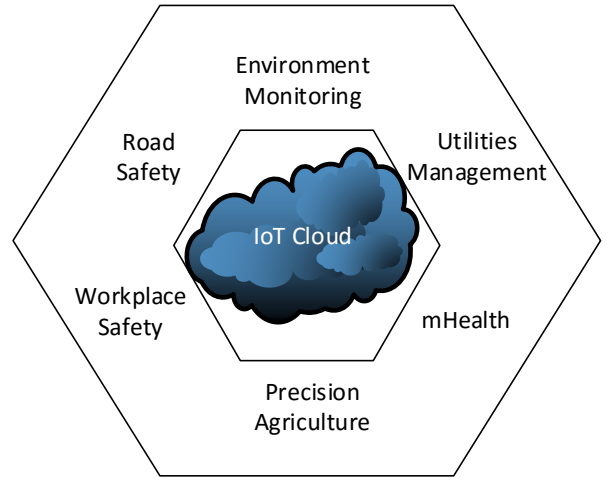


Fig. 1. Potential IoT applications in developing countries

ment, utility management, health monitoring and so on. Here, we focus on some of the significant fields.

A. Road Accident Mitigation and Transportation Safety

The developing countries are experiencing rapid growth in terms of economic development, population and consequently motorization. However, neither the sufficient road network nor the safe transportation techniques have been developed, resulting in an increased road safety problem. Driver distraction is one of the major causes of road accidents and highway crashes. Events and things that attract attention of the driver while driving are called distractions. More specifically, distractions are any type of events or causes that take away visual, manual and cognitive resources from the driving task. Estimations by the National Highway Traffic Safety Administration (NHTSA) show that driver distraction causes nearly 25% of police reported crashes [4]. Approximately, 80% of crashes and 65% of near-crashes involve some form of driver distraction and the distraction occurs within three seconds of vehicle crash [4]. As a result, it is an interesting and timely research field to work in in the aim of mitigating road accidents and ensuring transportation safety, utilizing the best of IoT.

We can deploy smart devices to collect the data that indicate the cognitive responses of the drivers, their mental and physical health, the vehicles' fitness and safety measurements, etc. Collecting the data makes it possible to take safety measures like, alarming the driver or responsible authorities, intelligently stopping the vehicle, restricting the fatigued driver from driving, etc. In summary, we can think of an Internet of smart vehicular systems to mitigate road accidents and enhance transportation safety.

B. Precision Agriculture

According to the United States Census Bureau, the world's population is over seven billion now, and it is expected to

increase more than three billion over the next few decades. As a result, the food demand will grow 1.5-2 times more than what it is at presently [5]. Besides, the farm economy is becoming unstable due to the combined effect of the volatile nature of agricultural conditions and the uncertainty of expected income from farm products. In the developing countries, the scenario is worse and becoming more abnormal day by day. Natural calamities, lack of proper fertilization, use of excessive chemicals and pesticides, inefficient crop monitoring systems lead the crop management system of these countries to jeopardy. Moreover, usage of poisonous chemicals like Formaldehyde to prevent food from becoming rotten urges for effective food monitoring systems. The prospect of Precision Agriculture (PA) is reflected in many recent researches. According to Global PA Market Analysis & Forecast (2015-2022) by BIS Research, the global market size for PA has been estimated to grow over \$6.34 billion by 2022.

These conditions necessitate the usage of modern technologies to improve crop-planning, to facilitate the better in-field management decisions, to provide precise farm records, to minimize the usage of fertilizers and pesticides to the optimum level, to maximize profit margin and finally to reduce environmental pollution. In contrast, the solution remains in a very elementary stage. In fact, the adoption of sensor and actuator devices in implementing PA systems is very limited and still in research farms worldwide. PA might help in ensuring accurate utilization of plant nutrition materials, to protect them from insects and diseases, and finally to yield higher crop production. Moreover, PA actually provides a better scope for the national policy makers to plan for the future production of crops and helps them to develop the right methods to maintain food security.

C. Environment Monitoring

Environment monitoring is a growing paradigm in the field of the Internet of Things and is becoming a key feature of modern environment management systems. Reusable hardware and software platforms and energy harvesting sensors [6] can be exploited to facilitate IoT application requirements for ameliorating the current environment monitoring systems. In developing countries, the necessity of modern environment monitoring is very high. There, the rate of air pollution, noise pollution, industrial pollution, and a range of human created environmental pollution is formidable. To mitigate the pollution level, we need to monitor the environment both in urban and rural areas. In the developing countries, it is important to monitor the environment regularly to predict the climatic changes and to deal with the natural calamities like, cyclones, flood, drought, etc. In these countries, the system needs to be fairly cheap and easily maintainable. So, usage of IoT in environment monitoring can open a new era of opportunities to maintain the consonance of nature, climate and civilization.

D. Utility Management

Utility Management is one of the most prominent fields in respect to the application of IoT in the developing world. In addition to electricity, gas, trash removal, etc., water network monitoring and quality assurance of drinking water is considered as a significant application of IoT. To ensure high water supply quality, sensors that measure critical water parameters are installed at prime locations [7]. The whole monitoring system is managed by an Internet backbone consisting of high speed fiber optic networks and Cloud services.

In developing countries, there is virtually no utility except electricity, which is being managed utilizing modern monitoring systems. Even for electricity, the whole system needs a lot of manual inputs from management personnel. So, in these countries, it is important to implement smart and cost-effective systems that will benefit people with efficient utilization of available resources and minimize the resource wastage.

E. Intelligent Health Management (mHealth or eHealth)

In this age, the cliché of global aging and chronic diseases is becoming a regular phenomenon [8]. To deal with the situation, many developed countries are focusing on reducing hospital beds and in contrast, they are building up intelligent home health-care systems. These kind of systems are the combination of Hospital-centric services and Home-centric environments. Implementation of the systems by developing practical and advanced health related technologies by exploiting IoT is becoming a burning research issue [9].

Developing intelligent health monitoring systems is becoming important for some other reasons, such as, real-time health monitoring which helps to detect and predict formidable health issues and to take precautions. Moreover, almost 25% of young people do not intend to follow the proper prescriptions from the doctors. Consequently, the necessity of continuous health monitoring is gaining significance day by day. IoT enables the easy access of Internet to health sensors, actuators and other devices and provides Cloud services to manage data and system integrity. Thus, IoT creates an opportunity to utilize ICT in respect to develop health intelligent management systems.

In developing countries, the scenario is grimmer than the developed world. Here, from the birth of a child, ending up to the chronic diseases of aged persons, the degree of irregularity in health management is immense. People are not really concerned of their health and they do not even bother to preserve their medication history. People often come to see doctors when they are in the final stage of cancer. So, the scope of utilizing intelligent health management systems is huge. IoT envisions a way to implement eHealth with robust and affordable services in developing countries.

F. Workplace Safety Enhancement

In developing countries like Bangladesh, Vietnam, India, etc., work safety is often ignored to save capital and invest in production more. Although the governments impose strict laws to prohibit disasters and accidents in workplaces, it is

a very common practice of the industry authorities to bypass the restrictions with the help of corrupted officials. So, the situation asks for a solution that should be cost effective, easy to use and well-integrated. A well organized workplace monitoring system can ensure reliable and corruption mitigation procedures for meeting the safety standards in industry.

In recent years, a number of industry incidents happened that point to serious safety ignorance and lack of modern safety monitoring systems. The 2012 Dhaka fire killed more than 117 garments workers at the Tajrin garments factory in Bangladesh. Again, the Rana Plaza incident in 2013 killed an overwhelming number of more than 1100 people and injured more than 2500 people in Bangladesh. These incidents indicate the substantial necessity of well integrated safety monitoring and warning systems. In these circumstances, IoT opens the door of hope to sort this problem out.

G. Social Security Management

The current conditions in developing countries reflect the lack of Social Security. The situation, especially in India and Bangladesh, indicates an unsafe state for general people, especially for women. The rate of street harassment to women is very high and the condition is becoming grimmer day by day. Nights are becoming dangerous due to an uncountable number of thefts, robberies, hijackings, kidnappings, murders, rapes and so on. In fact, the growth of terrorism and civil unrest in developing countries put things to their worst. To get rid of them, we need to provide a whole new system of social security networks. The technologies ranging from a central CCTV network to personal safety devices can be used to make cities safer. We have all the technologies in hand to integrate and the platform is IoT. So, it is a great prospect for IoT to develop social security ensuring systems.

III. CHALLENGES OF IOT IN DEVELOPING COUNTRIES

The prospect also brings a whole bunch of challenges. In developing countries, the administrative and financial systems run by mostly without any integrated and automated system. The level of technology usage is low, and the investment on research and development is very little. In the following sections, we focus on various IoT challenges in detail in respect to developing countries.

A. Technical Challenges

1) *Internet Connectivity*: Internet Connectivity is a prime issue, when we want to enable IoT. Internet of Things demands flawless and adequate connectivity among every particular *thing*. To sustain flawless connectivity, it needs fast internet speed, a continuous power supply, robust backup systems and reliable and scalable infrastructure.

Facilitating the end users with high speed internet in developing countries is a huge challenge. To deploy wired backbone throughout the whole country is formidably costly, and it is kind of impossible for them to develop a countrywide wired network to facilitate every end-user. An easy alternative is to provide internet access through wireless technologies, like 3G,

WiMAX, 4G-LTE, etc. This invokes other kinds of problems concerning lower internet speed, high power consumption, high cost per unit usage ratio, etc.

So, the authorities can deploy a hybrid model of internet backbone over the whole country, consisting of a fiber-optic national data-highway, local and national data centers, regional WiMAX and 4G service points, etc. The main challenge here is to deploy a hybrid backbone over the country, that trades-off with the problems and facilitates the end-users with optimal utility, that can be sufficient to enable IoT in these countries.

2) *Data Centers*: The creation of unmatched amounts of data is one of the most important offshoots of the IoT. Since the Internet consumes up to 5% [10] of the total energy generated today and with IoT demands on the rise, energy consumption is guaranteed to rise as a consequence. Data centers in developing countries that are run on harvested energy and are centralized will cater for energy efficiency and reliability. The storage of data thus has to be implemented intelligently so that smart monitoring and actuation can take place.

3) *Power Resources*: Compared to developed countries, the planning of electricity for developing countries presents itself as a complicated dilemma. The challenge surpasses the mere acquisition of financing for energy related investments. Energy development is challenging as electric power industries are among the most intensive in an economy. This leads to the severe draining of financial resources.

IoT for developing countries (IoT4D) will aid in providing power solutions by enabling clean energy technologies, creating smarter energy markets and by optimizing the implementation of existing products. For example, to improve the use of energy in homes, the IoT will automate and promote energy efficient practices such as the running of appliances at off-peak times.

In terms of a solution presented by IoT, servicing customers with information regarding utilities, devices known as smart meters can provide real-time, two-way communication between customers and devices in their perusal. Benefits involve granular detail to customers about their electricity usage. Smart meters also aid customers in modifying their energy consumption in relation to current prices. A smart meter also allows the collection of data automatically. This negates the need for a company needing to send out an engineer to manually collect data readings from such a meter. It also serves as an effective means to detect outages and the necessity of repairs [11].

4) *Human Resources*: A great challenge is the lack of technically knowledgeable personnel. They include Engineers, Scientists and Technicians. IoT is a state-of-the-art term and implementing the technologies to build up IoT platforms requires learned personnel. In developing countries, the number of research centers are very low. The funding and investment to innovations is critically at nadir.

B. Device Reliability

IoT devices for developing countries need to be robust, energy efficient and able to run on batteries for months at a time. They also need to be able to make use of the solar radiation present for recharging capabilities (e.g., photo-voltaic panels). Even the sensors connected to motes in areas where they are exposed to environmental factors need to be of a high quality and have a reasonable life span. These devices should be designed in a modular fashion that makes components easily replaceable, almost in a plug-'n-play manner.

It is important to know when an IoT device drops off from a network and goes offline. Knowing when the device comes back online is equally important. It is in this domain that presence detection is able to give an exact and up to date status of all devices that form part of a network. The monitoring of IoT devices in this way lends the ability to correct any problems that have arisen within a network. It subsequently boosts its reliability.

C. Financial Challenges

The IoT provides a great opportunity for developing countries to leapfrog from poorly prepared to scientifically and technologically equipped countries which can use the IoT technology to face their current and future challenges by tapping into the potential provided by this technology. However, such opportunity may become reality only if the developing world is ready to embark into this technology at the same pace as scientists and technologists of the developed world and financial challenges related to these technologies are addressed. These include low cost of acquisition, maintenance and financial sustainability.

As currently perceived, sensor devices are the raw material of the IoT. Such devices are still expensive for many countries of the developing world when accounting for the cost of acquisition and shipping from the manufacturing companies which are mainly located in the developed countries. This may hamper their wide and ubiquitous deployment in the developing world. Furthermore, for such devices, cost and field-readiness are still closely related while the most field ready devices are usually proprietary devices with vendor-locked software, sometimes updated frequently at recurrent fees or cost. This leads to higher cost of maintenance and operation which also leads to a challenging financial sustainability situation for those operating IoT businesses. Many of these challenges may be addressed through local IoT expertise, the use of open source hardware and software, and strong collaboration between scientists and technologists of the developed and developing world. Such collaboration will enable the IoT4D dream to become reality.

D. Security, Privacy and Trust Issues

IoT security is a topic that is still in its development stage, though there exists a rather large volume of research that analyzes the challenges it presents and possible means of safe guarding against attacks. These challenges must be overcome in order for the IoT to be ready for real world deployment.

Since IoT architectures can be complex and can scale to accommodate billions of objects or things that interact with each other and with other entities, such interactions must be secured.

The complexity presented by large scale architectures allow for attack vectors that can be capitalized on in a staggering way as access by anyone, anyhow and anytime are key features of the IoT [12]. IoT threats are numerous and include attacks that target various communication channels, denial of service, identity fabrication, physical attacks, etc.

In terms of protocol and network security, efficient cryptography algorithms are needed that can provide a high throughput even in 8-bit devices. These algorithms should also be lightweight by design and offer end-to-end secure communication channels.

Key management systems must be implemented that take care of distributing credentials to these protocols. These credentials will aid in establishing session keys between nodes.

Another factor of concern is authentication to cater for identity management. Authentication would allow the vetting of data to ensure that it contains what it is supposed to contain. The sheer number of nodes involved in an IoT network that creates information can be a large threat to privacy. Users involved in a sensor system or network should have tools provided to them that caters for anonymity amid connected networks. This will afford users a means of trust.

Awareness mechanisms should be put in place that can detect intrusions and even prevent them. This will aid IoT objects in protecting them or even gracefully degrading their services. Recovery services must be able to determine areas under attack and redirect the systems' functionality towards trusted areas in an IoT network.

IV. SOLUTIONS AND WAY FORWARD

As we described in the previous section, there are many challenges for IoT in Developing Countries. We believe that the solutions to these challenges are already available and that Developing Countries will leapfrog ahead of industrialized countries in adopting IoT.

1) Technical Challenges

- **Connectivity:** IoT networks will require hybrid solutions. Developing Countries host more than 70% of SIM cards in the world and most countries have extensive mobile coverage. M2M solutions [13] based on GSM are therefore feasible right now [14]. When talking about long distance wireless links (necessary to cover big distances as frequently the case in Africa), solutions in the ISM bands don't require any license. Several satellite solutions are available at reasonable costs for areas where there is no GSM coverage. Finally, Disruptions Tolerant Networking (DTN) based solutions for sensor networks have been studied and tested for areas where human mobility is guaranteed (most big urban centers).
- **Internet connectivity:** Internet connectivity is vital to IoT solutions. The solution here is the segmen-

tation of geological area coverage. Sensor data are mostly useful in the communities where they are collected. So, it is desirable that we can build up local segments of the whole system so that we don't need to synchronize all the data in real-time over the Internet to the central servers. So regions with limited Internet connection can still benefit from the rich data coming from Wireless Sensors. Fantacci et.al.[15] proposed a efficient network architecture for this solution.

- Power: reliable power supply is a big challenge in most of the Developing World. Solar and Wind are clearly the effective solutions. In contrast, establishing the power plants of Solar and Wind are not linear in cost. For example, if you double the size the cost will be more than double. IoT nodes require very little energy, so small solar panels are suitable and are very cheap. In addition, energy harvesting sensors are adding a new paradigm to the play-field [16]. Deploying and maintaining energy harvesting sensors is cheap and easy. It can conveniently ease the demand of power.
- Data Centers: there are several examples of low energy data centers and they are all powered by solar energy which is abundant in Developing Countries.

2) Social Challenges

- Standardization: the lack of a standard is listed as a limiting factor for the success of IoT. While this is true for the Industrialized World, it can be seen as an opportunity for the Developing World. There is no definitive standard in IoT, so the needs coming from the Developing World (long battery life, support of different wireless technologies, longer wireless links using TV White Spaces, etc.) can still be satisfied by a new standard.
- Case Studies: what is needed to define clearly the standardization requirements is more case studies. By critically analyzing the lessons learned from deployments, the IoT community can define features that need to be standardized.
- Human Resources: this challenge includes training engineers and scientists on IoT and final users on the benefits they can obtain from this new technology. Policy makers need to understand what benefits they can gain from the explosion of data coming from IoT networks. Finally, a network of IoT practitioners from the Developing World can exchange experiences and drive this technology further.

V. CONCLUSION

In this paper, we present the opportunities that IoT can offer in developing countries. The potential applications are countless and they can help optimize processes with a direct impact on society. We then listed a number of challenges that have to be addressed to make this new technology successful. Finally, we showed that some of the challenges can be turned

into opportunities and that IoT has good chances to succeed in developing countries.

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