Harnessing the Internet of Things for Global Development

A CONTRIBUTION TO THE UN BROADBAND COMMISSION
FOR SUSTAINABLE DEVELOPMENT

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Acknowledgements

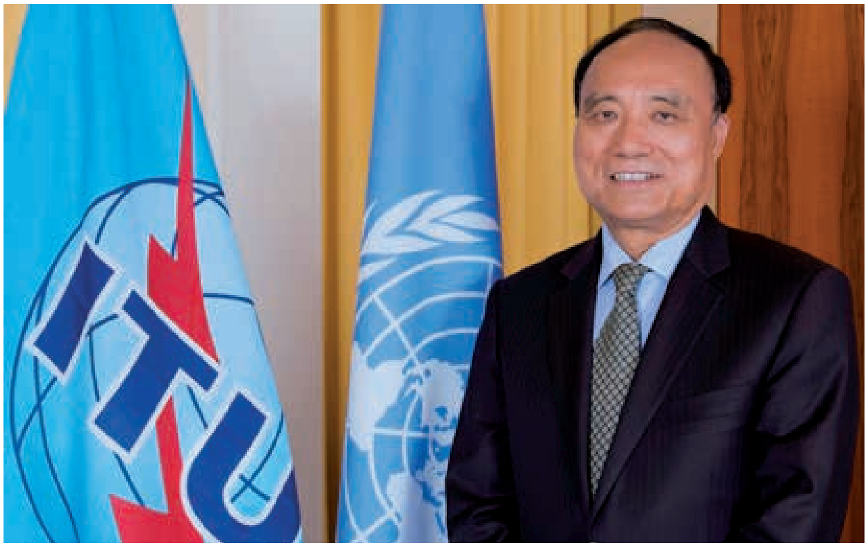
This report has been written by Phillippa Biggs (ITU), John Garrity (Cisco), Connie LaSalle (Cisco) and Anna Polomska (ITU), under the supervision of Dr. Robert Pepper (Cisco) as a contribution to the ITU/UNESCO Broadband Commission for Sustainable Development.
Mitch Husle and Mary Carol Madigan provided research support, with additional review provided by Dr. Ruba Borno (Cisco).

The authors wish to thank the following people and organizations who generously contributed their time and insights through interviews and discussion to this report (listed alphabetically by organization/project, and individual's name):

- American Red Cross (Abi Weaver)
- DAI (Robert Ryan-Silva)
- Echo Mobile (Zoe Cohen, Jeremy Gordon)
- Integra (John Waugh, Eric White)
- International Center for Theoretical Physics (Marco Zennaro)
- Kopernik.info (Edwin Mulianto)
- Network Startup Resource Center (Jonathan Brewer)
- NexLeaf Analytics (Martin Lukac, Nithya Ramanathan, Shahrzad Yavari)
- Oxford University - SmartPump Mobile Enabled Transmitter (Patrick Thomson)
- Portland State University - SWEETSense, Inc. (Dexter Gauntlett)
- Rainforest Connection (Dave Grenell)
- United States Forest Service (Dr. Lindsey Rustad)
- University of California Center for Effective Global Action (Temina Madon)
- University of Washington - Smart Connect (Richard Anderson)
- Wadi Drone project, NYU Abu Dhabi (Matt Karau, Martin Slosarik)
- WellDone – MoMo (Austin McGee, Tim Burke)
- World Agroforestry Center (Siddharth Mohan)
- World Bank (Edward Anderson)

The views contained in this report may not necessarily reflect the views of the ITU or Cisco Systems.

*Front cover image: Achieving the Sustainable Development Goals (SDGs) with the Internet of Things



Foreword by Mr. Houlin Zhao, ITU Secretary-General

After more than a decade of discussion and anticipation, the Internet of Things is now firmly on its way. This is a major development, which promises to extend our online world in a myriad of ways. Connecting things, as well as people, offers prospects of new ways of monitoring situations, learning and responding in real-time.

In some sense, the "Internet of Things" is a misnomer. The Internet of Things is not a single, unified network of connected devices, but rather a set of different technologies which can be put to work in coordination together at the service and to the ultimate benefit of people in both developed and developing economies. This set of Internet of Things technologies is realizing a vision of a miniaturized, embedded, automated environment of devices communicating constantly and automatically. However, connecting up devices or robots (whether they are bridges, fridges or widgets) is only a means to an end – the really interesting part arises in terms of what can be done with the data obtained, and the learning outcomes for improving our future.

While researching this report, my staff learned it is not possible to focus solely on the technologies, at the risk of ignoring the human context in which these technologies must work. There are many difficult trade-offs involved – only some of which are technological (for example, the trade-off between robustness and reliability, and the sophisticated functionality of sensors on a water pump). Other trade-offs enter into broader issues (for example, gaps between technical security and users' perceptions of security and trust, or the detailed information yielded by geo-localization technologies). Moreover, the purpose for which technology and applications are developed does not always end up as the sole – or even major – purpose for which they are actually used.

This report raises many important questions. Nevertheless, asking the right questions is also an important part of any learning process, and I welcome this report's thoughtful exploration of the use and applications of some of these different technologies in the context of developing countries.

Houlin Zhao
ITU Secretary-General

Foreword by Mr. Chuck Robbins, CEO, Cisco Systems

At Cisco, we believe that technology has the capability to transform lives. Over the past few years, we have seen companies, cities and countries move to digitize all that they do, driving positive results in numerous ways. Yet across the world, many people still must confront a number of difficulties from climate change, endemic poverty, and environmental degradation, to the lack of access to quality of education, and communicable disease. While these big issues might seem insurmountable, we believe that technology can play a critical role addressing many of these challenges, while creating a host of opportunities.

Today, the Internet of Things is improving the day-to-day lives of citizens around the world. In cities from Barcelona to Songdo to Rio de Janeiro, Internet Protocol (IP)-connected sensors are monitoring traffic patterns, providing city managers with key data on how to improve operations and communicate transportation options. Similar information flows are improving hospitals and healthcare systems, education delivery, and basic government services such as safety, fire, and utilities. Sensors and actuators in manufacturing plants, mining operations, and oil fields are also helping to raise production, lower costs, and increase safety.

In both developed and developing countries, the Internet of Things is also helping monitor critical vaccines through the use of IP-connected thermometers. Moisture sensors in agricultural fields now alert farmers to the exact needs of food crops, and acoustic sensors in protected rainforests are helping to curb illegal logging.

For the IoT to have an even greater impact, there is still more we can do to improve the deployment of these technologies in developing countries. Network deployment, power requirements, reliability and durability are all uneven, at best, and policy considerations concerning access to data, legacy regulatory models, standards, interoperability, security, and privacy need to be addressed.

We are in the early stages of IoT adoption and are pleased to see the great impact that the IoT is already making for people, companies, industries and countries around the world. This report aims to serve as a guide for how the IoT can be fully utilized to improve the lives of people everywhere. The application of the IoT to solve many of the world's challenges is limited only by our imagination.

Chuck Robbins
CEO, Cisco Systems

Executive Summary

This report explores the current use and potential of Internet of Things (IoT) technologies in tackling global development challenges, highlighting a number of specific instances where IoT interventions are helping to solve some of the world's most pressing issues. It presents summary conclusions on what is required for the IoT to reach billions of people living in the developing world, and also to accelerate income growth and social development as a result.

Information and communication technologies (ICTs) such as mobile phones, Internet use and Big Data[1] analytics are pervasively utilized in global development projects (in a field often known as ICT for Development, or ICT4D) to improve outcomes and deliver services. Recently, this field has experienced strong growth. For example, in a recent presentation, Carolyn Woo, CEO of Catholic Relief Services (CRS), identified 157 new development assistance projects, each started by CRS between 2014 and 2015, that incorporate ICTs (primarily mobile telephony[2]). Similarly, at Johns Hopkins University alone, as of May 2015, there were over 140 mHealth (mobile phone-enabled healthcare) projects across the developing world.[3] And an April 2015 review at the World Bank identified at least thirty-two projects that specifically incorporate Big Data analytics.[4] As evidenced by these examples, mobiles are highly integrated in development projects already. Connected sensors and M2M connectivity represent the next frontier in the ICT4D story.

After having been coined as a term in 1999 by Kevin Ashton,[5] and after more than a decade of discussion and anticipation, the Internet of Things is finally emerging. This is a major development, which promises to change our way of doing things through better information in real-time and improved learning opportunities. IoT is closely related to the concepts of Machine-to-Machine (M2M) communications and Wireless Sensor Networks (WSN) on the connectivity side, and to Big Data in terms of the content outcomes produced. The IoT also comprises the data produced and transmitted between machines (M2M), as well as between machines and people (M2P). Key elements include machine-produced data (e.g., from sensors), and the communication of that data (via connectivity technologies).

Many different stakeholders are involved in active IoT projects on the ground, including industry members, universities, NGOs, and tech start-ups, each contributing different strengths. The IoT is not just a story for industrialized economies or industrial applications, but is equally relevant for developing countries. The IoT and connected sensors are driving improvements to human wellbeing in healthcare, water, agriculture, natural resource management, resiliency to climate change and energy (as reflected in the UN's post-2015 sustainable development agenda). The research for this report uncovered many interesting examples and applications of the IoT in developed economies. However, these are beyond the scope of this report, which focuses on impactful applications of the IoT for developing countries.

When determining which IoT application fits best for a particular context, there are many trade-offs and compromises involved. Technical trade-offs include different characteristics among connectivity technologies, including, but not limited to: performance, efficiency, reliability, robustness, flexibility, range, power requirements, data throughput, cost (of sensors, connectivity modules and service) and licensed versus unlicensed spectrum. For large-scale systems including hundreds of thousands of sensors, devices and/or readers, high reliability levels are likely to prove important. Cultural context on the ground also matters, and it should be taken into account, along with technical considerations.

Huge new opportunities are now opening up through improved access to and use of Big Data techniques, which offer learning opportunities to improve real-world processes and enhance decision-making over the

1 "Big Data" refers broadly to a data set, comprised of structured or unstructured data, so large or complex that traditional data processing applications are not sufficient for analysis.

2 Keynote presentation by Dr. Carolyn Woo of Catholic Relief Services http://schd.ws/hosted_files/crsict4dconference2015a/84/2015%20ICT4D%20Conference%20Welcome%20Presentation%20Final.pdf

3 Keynote presentation by Dr. Alain Labrique of Johns Hopkins University at the Catholic Relief Services 2015 ICT4Development Conference, Chicago, May 27, 2015.

4 "Big Data for a More Resilient Future", World Bank Group/ 2015 Spring Meetings, Big Data for Development, Summary of Projects.

5 Kevin Ashton, "That 'Internet of Things' Thing, in the real world things matter more than ideas," RFID Journal, June 22, 1999.

short-, medium- and long-term in healthcare, education, emergency services and disaster response, among a variety of other application areas.

Impactful IoT interventions in development can improve efficiency (achieving similar levels of impact with fewer resources) and/or enhance effectiveness (increasing impact with similar levels of existing resources). In advancing global development, IoT interventions are helping to improve research, public policy, basic service delivery and the monitoring and evaluation of programmes across a range of different sectors. This report discusses examples of use cases of the IoT in healthcare, water, agriculture, natural resource management, resiliency to climate change and energy.

The IoT has regulatory implications across the areas of licensing, spectrum management, standards, competition, security and privacy – only some of which are the familiar territory of telecom regulators, compared to other domains where non-telecom regulators may typically take the lead.

Maximizing the benefits of the IoT is likely to require more coordinated regulation across all sectors, with telecom/ICT regulators working closely with their counterparts in data protection and competition, but also with emergency services, health and highway authorities.[6]

Laws and regulations on data will need to be reconsidered carefully in view of the IoT – in terms of how data are obtained and can be used, how long data can be kept, limits on access by third (fourth or fifth… nth) parties (the term 'third party' may prove woefully inadequate in some cases). The information collected from sensor systems may or may not be freely accessible on the Internet (Open Data), and the data transmitted may or may not cross the public Internet.

Given the high pervasiveness of the IoT's impact, it is vital that as more countries introduce policy frameworks, they take into account the various factors and implications of the IoT across different sectors. When all stakeholders are included in active dialogue, the IoT represents a promising opportunity for more coherent policy-making and implementation.

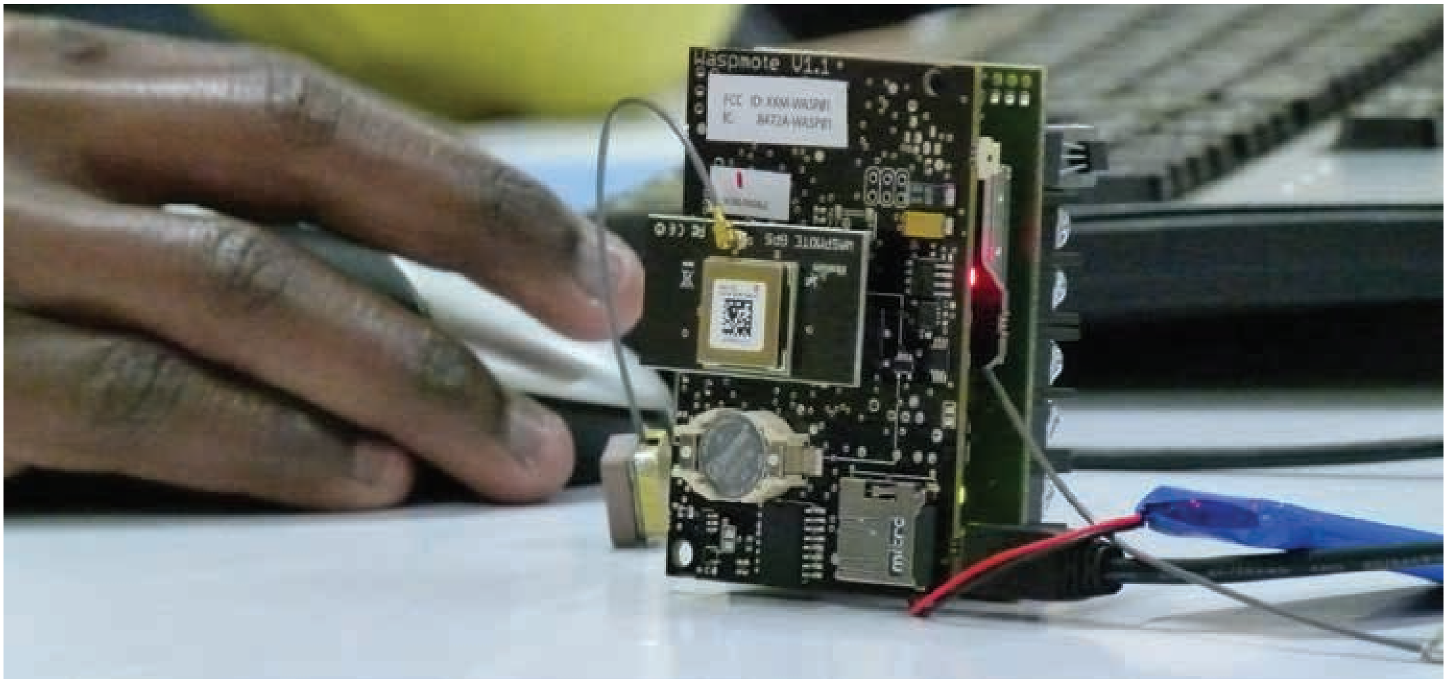


Photo credit: Marco Zennaro. GSM connectivity node in Nairobi.

6 "Regulation and the Internet of Things", GSR-2015 Discussion Paper, available at: www.itu.int/en/ITU-D/Conferences/GSR/Documents/GSR2015/Discussion_papers_and_Presentations/GSR_DiscussionPaper_IoT.pdf

Extending our Hyperconnected World through the IoT and Big Data

Photo credit: Marco Zennaro. Solar-powered, Wi-Fi enabled soil moisture node at the Asian Institute of Technology in Bangkok.

Defining the Internet of Things

After more than a decade of debate, discussion and anticipation, the 'Internet of Things' (IoT) is finally emerging. As early as 2005, the ITU noted that the development of the Internet of Things as a function of our hyperconnected world encompassed a set of technological advances from different fields – specifically, wireless and mobile connectivity, nanotechnology, radio-frequency identification (RFID) and smart sensor technologies.[1] Advances in these technologies, when combined, could help realize a miniaturized, embedded, automated Internet of connected devices communicating regularly and relatively effortlessly.[2]

Today, governments, businesses, and consumers are using the IoT and Big Data to introduce new business models, to improve the delivery of services, to increase efficiency in production, and to enhance wellbeing and human welfare. As with many other technologies, vendors, implementers, operators, policy-makers and regulators aim to maximize the benefits of deployment while minimizing potential risks to security and privacy.

Widely disparate definitions of the IoT exist. The ITU has defined the IoT as "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" (Recommendation ITU-T Y.2060).[3] The IoT clearly includes M2M (referring specifically to communication directly between devices, used in a vast array of applications and for a variety of purposes[4]), but broader definitions of IoT technologies also include ambient intelligence and smart environments.

For example, ABI Research separates the "digital-first" domain (e.g. PCs and mobile devices, designed mainly as digital devices) from the "physical-first" domain (e.g. humans and other, hitherto unconnected "things"). ABI Research also notes that despite the ongoing convergence of these two distinct domains, there is still only one overarching Internet through which the domains connect.[5] A 2012 Machina-GSMA study distinguishes "mobile-connected devices," which connect directly to a mobile network (usually via a SIM card) from the broader "connected devices" market, which includes "short-range devices" (e.g., devices using Wi-Fi, Bluetooth and/or other connection technology).[6]

The UK regulator OFCOM differentiates between the two related terms:

- M2M: describing the interconnection (usually via wireless technologies) of devices that would not previously have had the ability to communicate (e.g., connected cars).
- The IoT: a broader term describing the interconnection of multiple M2M applications, often enabling the exchange of data across multiple industry sectors (e.g., the ability to manage traffic flow, reduce pollution and improve health by combining data from a range of transport, healthcare and environmental sensors).

Deloitte sees M2M as a category that has become broader over time, encompassing all types of telematics over cellular networks on trucks, smart utility meters, eReaders, tablets and PC modems, but excluding smartphones.[7] They suggest that it is inappropriate for M2M to include eReaders, tablets and PC modems since, "although there is the occasional automatic data upload or download, most of the traffic via these devices is human-initiated and human-observed." On this basis, Deloitte excludes smart TVs, games consoles and set-top boxes from its predictions. The research consultancy GP Bullhound agrees that it is the automatic

1 ITU (2005). "ITU Internet Report 2005: The Internet of Things." Available at: www.itu.int/osg/spu/publications/internetofthings/ and www.itu.int/osg/spu/publications/internetofthings/InternetofThings_summary.pdf.

2 Opinion is divided on how many of these connected devices really need to interconnect and communicate with each other at any point of time. Some commentators suggest only 2% of devices need to communicate (for a specific purpose). The 'smart environment' vision foresees nearly all devices within an 'environment' communicating.

3 ITU-T Recommendation Y.2060, note, s.8.4.

4 For example, Vodafone has defined M2M as "remote wireless data interchange between two or more devices or a central station that allows remote monitoring and control of devices and processes." See Vodafone press release on 29 April 2010. "M2M : A new way of working." Available at: http://enterprise.vodafone.com/insight_news/2010-04-29_a_new_way_of_working.jsp

5 https://www.abiresearch.com/market-research/product/1017637-internet-of-everything-market-tracker/

6 http://www.gsma.com/newsroom/press-release/gsma-announces-the-business-impact-of-connected-devices-could-be-worth-us4-5-trillion-in-2020/

7 Deloitte (2015). "Technology, Media and Telecommunications Predictions 2015," page 6. Available at: http://www2.deloitte.com/content/dam/Deloitte/global/Documents/Technology-Media-Telecommunications/gx-tmt-pred15-full-report.pdf

initiation of traffic and data exchange that is the distinguishing feature of M2M.[8]

The IoT is perhaps best understood as a set of related technologies that can be used together to achieve exciting ends, and it can be defined in terms of its contributing technologies, including the use of sensors, RFID chips, nanotechnologies and identification systems (chips, cards, SIMs), among others. Overall, IoT and various related technical developments (including convergence, cloud services, data analytics and the proliferation of sensors) are resulting in:

1. greater monitoring and measurement of humans, machines and things; as well as
2. a shift from human-to-human communications to M2M, something-to-everything, and everything-to-everything communications.
3. Greater and more rapid awareness of and information about status, function, and environment.

These different definitions of M2M, IoT, and what constitutes a "network-enabled device" result in widely varying estimates of the number of connected devices – depending on whether mobile, tablets, PCs, and wearables are included in definitions of 'connected devices'. It is unclear whether many of these estimates include wearables.

Gartner predicts that there will be 6.4 billion connected things in use worldwide in 2016.[9] However, in mid-2015, Cisco estimated that there were already 15.7 billion "devices connected to the Internet" – including mobile phones, parking meters, thermostats, cardiac monitors, tires, roads, cars, supermarket shelves and many other types of objects.[10]

Comparable estimates include:

- 25 billion 'networked devices' by 2020 (ITU);[11]
- 24 billion 'connected devices' by 2020 (Machina Research in conjunction with GSMA);[12] and
- 26 billion deployed IoT devices by 2020, a thirty-fold increase from 2009 (Gartner).[13]

These broad estimates are considerably higher than Analysys Mason's 2011 prediction that there will be 2.1 billion M2M device connections by 2020[14], which is based on a narrower definition of M2M.

However, other sources place this figure considerably higher still, including the well-known Ericsson estimate of 50 billion connected devices by 2020, a figure with which the Hamilton Project (Figure 1, page 12) agrees, after factoring in non-IP connected devices (such as RFID tags). ABI Research estimates that the installed base of 'active wireless connected devices' exceeded 16 billion in 2014, up 20% from 2013, and that it will more than double to 40.9 billion by 2020.[15]

Based on their definition, Deloitte estimates that IoT hardware could be worth around US$10 billion and IoT services worth around US$70 billion in 2015 alone.[16] Anecdotal reports from various firms corroborate the market size and opportunity.[17] ABI Research suggests that IoT hardware and connectivity revenues are growing at 10-20% annually, while apps, analytics and services are growing at 40-50% annually. Based on rapid growth, Gartner estimates that IoT product and service suppliers could generate incremental revenue in excess

8 GP Bullhound Technology Predictions 2015. Available at: http://www.gpbullhound.com/wp-content/uploads/2015/01/GP-Bullhound-Technology-Predictions-2015.pdf

9 http://www.gartner.com/newsroom/id/3165317

10 Cisco, Visual Networking Index 2015. Available at: http://www.cisco.com/c/en/us/solutions/service-provider/visual-networking-index-vni/index.html

11 "ITU Predicts 25 Billion Networked Devices by 2020", 28 September 2012, http://www.v3.co.uk/v3-uk/news/2207590/itu-predicts-25-billion-networked-devices-by-2020, via ACM TechNews.

12 GSMA, quoted at: http://www.gsma.com/newsroom/press-release/gsma-announces-the-business-impact-of-connected-devices-could-be-worth-us4-5-trillion-in-2020/

13 Gartner, Forecast: The Internet of Things, Worldwide, 2013, at https://www.gartner.com/doc/2625419/forecast-internet-things-worldwide-

14 S. Hilton, Imagine an M2M world with 2.1 billion connected things… Analysys Mason, 27 January 2011.

15 https://www.abiresearch.com/press/the-internet-of-things-will-drive-wireless-connect/

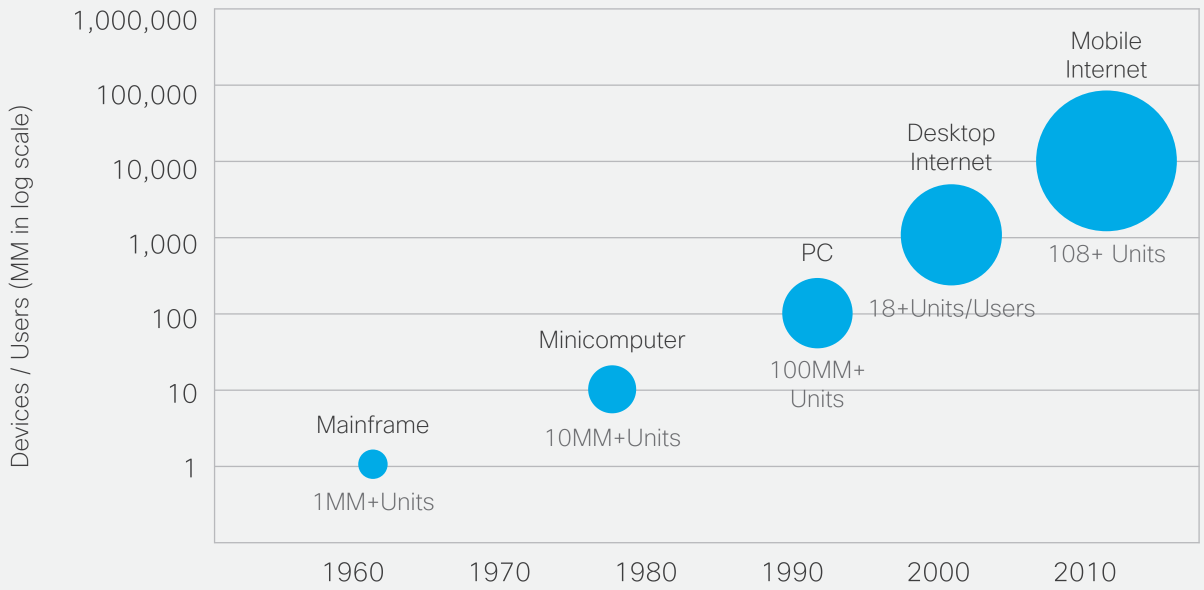
16 Page 6, Deloitte (2015), « Technology, Media and Telecommunications Predictions 2015": http://www2.deloitte.com/content/dam/Deloitte/global/Documents/Technology-Media-Telecommunications/gx-tmt-pred15-full-report.pdf

17 www.forbes.com/sites/aarontilley/2015/05/15/qualcomm-the-internet-of-things-is-a-billion-dollar-business/; http://bits.blogs.nytimes.com/2014/10/09/ge-opens-its-big-data-platform/?_r=0

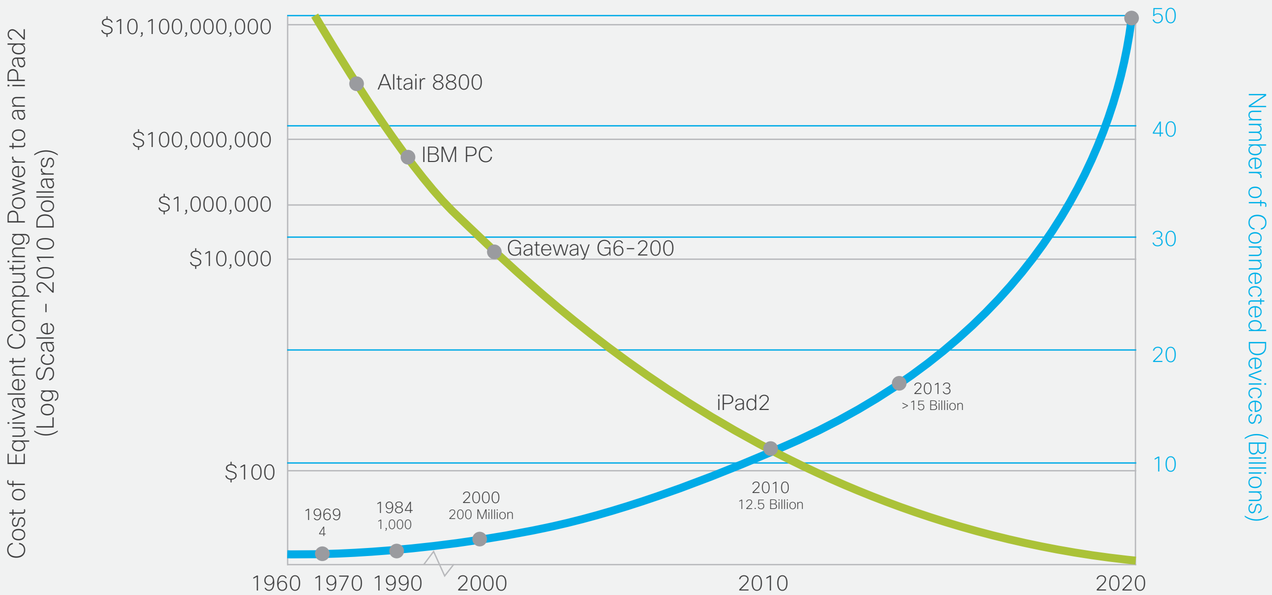
Figure 1: Miniaturizing & Multiplying - Getting Smaller & More Numerous

Each new computing cycle typically generates around 10x installed base of the previous cycle

Devices or users in millions; logarithmic scale



The cost of computing power is falling rapidly



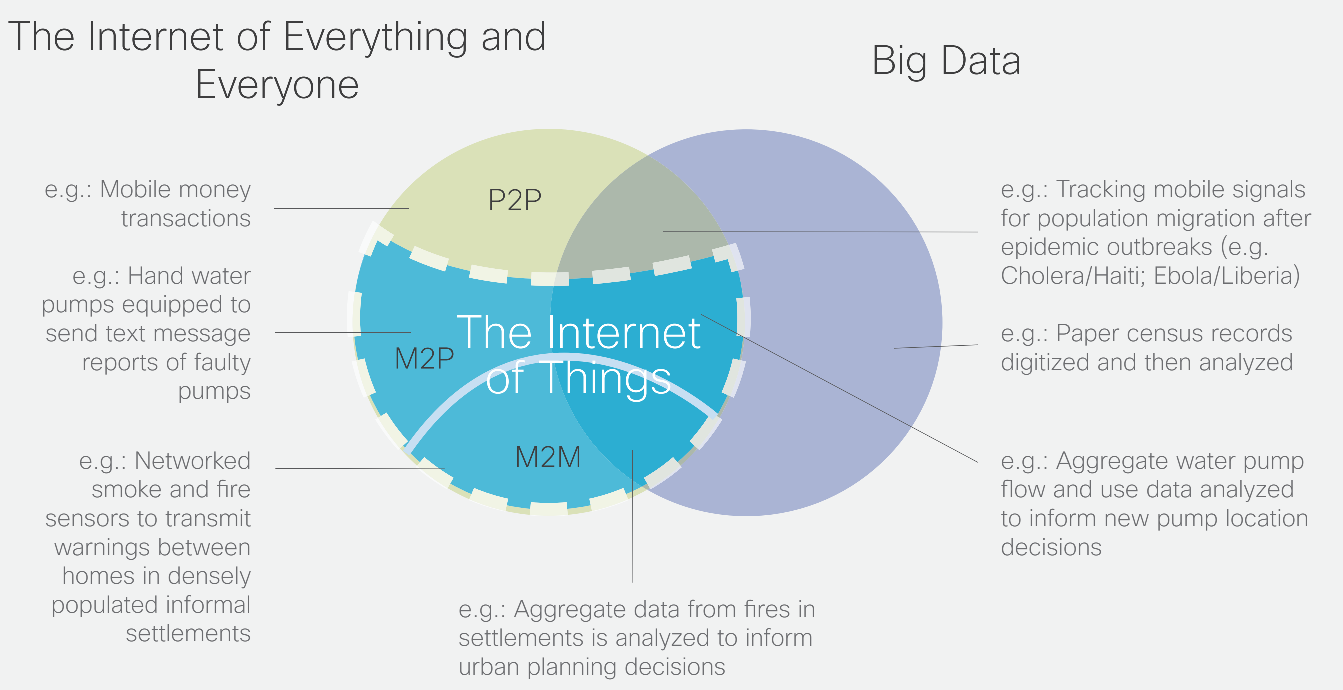
Sources: Mary Meeker's Internet Trends Report 2014 (top), available at: http://qz.com/214307/mary-meeker-2014-internet-trends-report-all-the-slides/; The Hamilton Project, Brookings Institute, Ericsson (bottom).

of US$300 billion by 2020, resulting in US$1.9 trillion in global economic added value.[18] IDC forecasts that the worldwide market for IoT solutions will grow from US$1.9 trillion in 2013 to US$7.1 trillion in 2020.[19]

The Internet of Things (comprising connected devices and connected environments, such as M2M and M2P) and Big Data are separate, but related, concepts. There is significant overlap between these two concepts, especially where data are collected and transmitted via connected devices and IP (Figure 2 below). Person-to-person (P2P) communications are direct interactions between individuals, facilitated by IP, such as emails, video conferencing, SMS and phone calls. Machine-to-person (M2P) transactions include machine-generated information communicated to individuals (such as automatic text messages from one's bank regarding account updates).

M2M communications include machine-generated data transmitted to other machines that process the data and determine which further actions may need to be taken. For example, onboard vehicle sensors transmit data on engine, transmission and wheel performance to a central processing capacity, which then determines at what point the vehicle may need to be serviced to prevent a breakdown. Simply put, the IoT involves machine-generated or machine-processed data that are communicated over IP.

Figure 2: The Intersection between IoT, M2M, Big Data and examples in international development



Note: P2P: Person-to-Person; M2P: Machine-to-Person; M2M: Machine-to-Machine.
Source: Cisco Systems.

18 www.gartner.com/newsroom/id/2684616

19 www.idc.com/getdoc.jsp?containerId=prUS24903114

These sub-categories in Figure 2 correspond roughly with ABI Research's categorization of the "Internet of Everything"[20] as a technology consisting of three subsystems:

- the Internet of Digital;
- the Internet of Things (broadly corresponding with M2M in Figure 2); and
- the Internet of Humans (broadly corresponding with Person-to-Person or P2P in Figure 2 above).

Another case in point is the purpose of IoT applications. These technologies benefit developing countries, in addition to their developed counterparts, in driving social and economic advancement. Services ranging from water and sanitation to healthcare, agriculture and beyond can be improved in the developing world through the implementation of IP-enabled sensors and actuators. Governments, development organizations, businesses and citizens in the emerging world are already incorporating the IoT and Big Data analysis to help alleviate some of the developing world's most pressing problems.

M2M is often used for telemetry, robotics, status tracking, road traffic control, logistic services and telemedicine. Vodafone notes that "M2M technology can be used for […] a huge range of applications including data collection, remote control, offsite diagnostics and maintenance, remote monitoring, status tracking, fleet management, traffic control and security systems".[21] Figure 3 illustrates

20 ABI Research definition available at: https://www.abiresearch.com/market-research/product/1017637-internet-of-everything-market-tracker/

21 Vodafone press release, "Delivering M2M communications for the global business", 30 April 2009, available from Vodafone press office at: http://enterprise.vodafone.com/insight_news/deliver_m2m.jsp.

Figure 3: From Individuals to Society – Examples of data generated by the IoT

Level	Individual	Community	Society
IoT	Smart phones Wearables	Connected Cars Health devices Smart homes	Smart Cities Smart Grids
Examples	GPS, Fitbits Visa PayWave Mastercard Paypass Employee passes	Intelligent Transport Systems Event Data Recorders (EDRs) Blood pressure monitors; remote burglar/heating systems	Smart metering; Smart water meters Traffic monitoring
Data	Mobile money Fitness data, GPS location-based data	Speed, distance, airbag, crash locations/alerts; Heart rate, blood pressure, Diet, remote heating data	Electricity/water consumption & billing; Traffic flow data
Intended Audience	Individual person Immediate friends/ family; banks; employers	GP, health authorities; health & car insurance; police, social networks	Authorities/regulators Utility companies; Other citizens

Source: Adapted from the ITU Draft GSR Discussion Paper 2015, "Regulation and the Internet of Things", Professor Ian Brown, Oxford Internet Institute, University of Oxford, UK.
Note: Individual smartphones can be used to connect cars or control smart homes through tethering, so there is some crossover between individual and car/home connectivity.

how IoT applications at the individual level (including GPS location, payment systems and wearables) can be aggregated up into applications for smart homes and connected cars. At the macro level, three of the areas of greatest IoT development and investment are smart cities (where infrastructure and building systems could improve the efficiency and sustainability of a range of urban activities), smart power, and water grids.

Wearables are included in the definition of the IoT for the purposes of this report, because most wearables either communicate directly with another device (e.g. heart rate monitors that connect via Bluetooth to a smartphone) or they connect directly and upload data to the Internet. This may sound like a large number of applications, but according to the GSMA, pure M2M connectivity and sensor networks may represent only a small subset of some of the broader use cases for 5G connectivity.[22]

How the Internet of Things is Emerging

The strong growth currently observed in IoT applications is attributable to several major underlying trends that are just now coming to fruition:

- The reduction in the cost of computing (including sensors) and the growth of Wi-Fi are enabling factors driving growth in IoT applications;[23]
- Growth in mobile and the deployment of data-friendly 3G networks from 2001 onwards, as well as the expansion of network connectivity across the world, and from urban to rural settings (including Wi-Fi, but also macro cell connectivity);
- The rise of software development, partly attributable to economies of scale; and
- The emergence of standardized low-power wireless technologies (as suggested by ABI Research[24]).

According to the ITU GSR 2015 Discussion Paper on regulation and the Internet of Things,[25] one possible explanation for why the IoT is advancing rapidly now is that it is moving from a position where it delivers incremental efficiency improvements to existing business models to one where it positively impacts new business models and processes as well.[26]

In terms of existing processes, the IoT can improve and enable a broad range of applications – from more efficient manufacturing, logistics, counterfeit detection, monitoring of people, stock, vehicles, equipment and infrastructure, to improved healthcare, traffic management, product development and hydrocarbon exploration.

In addition, the IoT is now also enabling the exploration of new business models such as car and truck rental clubs, whose members can book and use vehicles parked around their neighborhood almost on-demand; or "pay-as-you-drive" insurance based on driving patterns, behavior, and risk. For marketers, the IoT enables brands to gather more information about their customers, and create "truly compelling, magical experiences."[27]

Functionalities of the Internet of Things

Any IoT system includes a set of functions and parameters (Table 1, page 17), many of which are common to other types of connectivity as well. IoT systems can be defined according to a set of criteria in terms of their communications technologies, range, necessary bandwidth, number of nodes, robustness, reliability and/or power requirements (more often referred to simply as 'battery life').

Functionality

For any IoT scheme, a number of trade-offs are involved in performance, efficiency, reliability, robustness, flexibility, power supply, scalability, interoperability, ease

22 GSMA Intelligence (December 2014), "Understanding 5G: Perspectives on future technological advancements in mobile.

23 "Internet of Things By The Numbers: Market Estimates And Forecasts", Forbes, 22 August 2014, available at: http://www.forbes.com/sites/gil-press/2014/08/22/internet-of-things-by-the-numbers-market-estimates-and-forecasts/

24 https://www.abiresearch.com/market-research/product/1017637-inter-net-of-everything-market-tracker/

25 ITU Draft GSR Discussion Paper 2015, "Regulation and the Internet of Things", Professor Ian Brown, Oxford Internet Institute, University of Oxford, UK, at: www.itu.int/en/ITU-D/Conferences/GSR/Documents/GSR2015/Discussion_papers_and_Presentations/GSR_DiscussionPaper_IoT.pdf

26 ITU Draft GSR Discussion Paper 2015, "Regulation and the Internet of Things", Professor Ian Brown, Oxford Internet Institute, University of Oxford, UK, at: www.itu.int/en/ITU-D/Conferences/GSR/Documents/GSR2015/Discussion_papers_and_Presentations/GSR_DiscussionPaper_IoT.pdf

27 Andy Gilder. Beyond wearables: brands could capitalise on the Internet of Things. Memeburn, 6 June 2013.

of authentication, preservation of privacy, extensibility, mobility support, and modularity. For example, trade-offs may arise within the following:

- Complexity versus robustness (e.g. of sensors and connectivity modules);
- Range, data throughput, and cost (e.g. Wi-Fi vs LTE vs LoRa vs ethernet);
- Battery life versus data throughput. According to Cisco, new models of electrical generation and transmission (including batteries, simple chemical reactions, energy harvesting devices, etc.) will be needed to power the multitude of new devices that will emerge.[28] See Annex 2 for discussion on different battery life characteristics of different connectivity modules.
- High reliability levels may prove very important in large-scale systems using hundreds of thousands of sensors, devices and/or readers (e.g. for seismic monitoring networks around nuclear plants, but not necessarily for RFID tags on livestock).
- Low latency (the time required for round-trip data transmission) becomes all the more vital for advanced cloud computing applications (such as high-definition video conferencing and industrial collaboration), where any interruption or delay in data transmission can have major consequences.[29]

The choice of final specifications among the different options available depends on the aims of the deployment, and the challenges to be solved. For example, Figure 4 defines some of the technical characteristics of several different IoT applications.

28 Pepper, R. & Garrity, J. (2014) The Internet of Everything: How the Network Unleashes the Benefits of Big Data. Global IT Report 2014. WEF. http://www3.weforum.org/docs/GITR/2014/GITR_Chapter1.2_2014.pdf

29 Pepper, R. & Garrity, J. (2014) The Internet of Everything: How the Network Unleashes the Benefits of Big Data. Global IT Report 2014. WEF. http://www3.weforum.org/docs/GITR/2014/GITR_Chapter1.2_2014.pdf

Figure 4: Different IoT applications with Different Characteristics

Example Applications	Data volume	Quality of Service	Amount of signaling	Time sensitivity	Mobility	Server initiated Communication	Packet switched only
Smart energy meters	low	low	intermediate	very low	no	yes	yes
Red charging	low	low	low	low	yes	no	yes
eCall	very low	very high	very low	very high	yes	no	no
Remote maintenance	low	low	high	high	no	yes	yes
Fleet management	low	low	very high	intermediate	yes	yes	no
Photo frames	intermediate	low	high	low	no	yes	yes
Assets tracking	low	low	very high	high	yes	yes	no
Mobile payments	intermediate	low	high	very high	yes	no	yes
Media synchronisation	high	low	high	intermediate	yes	yes	yes
Surveillance cameras	very high	very high	low	very high	no	yes	yes
Health monitoring	high	high	high	very high	yes	yes	yes

very low | low | intermediate | high | very high

Source: *Handbook: Impacts of M2M Communications & Non-M2M Mobile Data Applications on Mobile Networks*, page 50. ITU (Geneva, 2012). Available at: www.itu.int/md/T09-SG11-120611-TD-GEN-0844/en.

Table 1: Functionality within IoT Technologies

Functionality	Examples
1. Location and mobility	Fixed or mobile location (e.g. GPS, GPRS) or for monitoring the status of the engine in a mobile car or on a flying drone.
2. Identification and addressing	For example, IP addresses, IMEI, chips, smart cards, SIMs.
3. Topology, architecture and node density and dispersion	This refers to the degree of dispersion of nodes within an environment. There may be many close together (a dense environment) or few far apart. In a very densely connected environment, an Internet of disparate connected devices may become a ubiquitous, fully connected environment (e.g. a connected hospital, smart cities). Topology takes into account the architecture and how nodes are constructed for reporting purposes (e.g. zone architecture or parent-child tree architecture with hierarchies).
4. Purpose	Detection/reporting of status. Many different types of sensors exist (e.g. thermal, moisture, optical, radiation, acoustic, kinetic, acoustic, chemical, position, instrumentation, motion, level, GPS coordinates) for monitoring a range of variables associated with tracking position (e.g. weather, climate, water, light, salinity, soils, vegetation, etc.) - see Figure 5 overleaf.
5. Efficient transmission/ exchange of information and performance	Centralized or distributed communications via central or local servers, central analysis and processing. In many developing countries with available mobile networks, communication modules rely on wireless connectivity (GPRS, 3G, WiFi, WiMAX, etc.). Data communications can be further broken down into other variables: • Range; • Routing: multi-hop or dynamic flooding; • Data volume and bandwidth needs – high or low; • One-way or two-way transmission capability; • The data may or may not be transmitted via the public Internet; • Latency and QoS of transmission.
6. Power system (aka battery life)	Independently operated or back-up power system. The battery life may have an important trade-off with the weight and/or complexity of the sensor. Some devices will need constant, wired power.
7. Dormancy versus regularity of communication	Some use cases for M2M require the connected device in the field to lie dormant for periods of time, or to use 'lean,' regular, or 'bursty' signaling (to note, continuous transmission has zero dormancy).
8. Alert/warning system	Commonly found in systems which alert to natural disaster. This may be binary (working/ fault; heart beat versus no heart beat) or set for the detection of motion (seismometer) or threshold (e.g. detection of pollution).
9. Automation	Automation/independent function – whether human initiation, monitoring or intervention is required.
10. Frequency of visit/ replacement	For maintenance and/or obsolescence and replacement.

Source: ITU.

Sensors

Much of the functionality of the IoT and the data transmitted in the M2M and M2P notions of the IoT are determined by the nature of sensor measurement. Other machines associated with the IoT include actuators, devices that can be directed to perform a physical activity such as opening an irrigation dam or closing a livestock fence. However, in the context of development, the majority of current applications utilize connected sensors.

As with the decline in the cost of computing power, the costs per unit of sensors have dropped steadily over time. Today, sensors are found in many everyday devices, and some of the latest smartphones come with at least ten embedded sensors, for example: a microphone to capture sounds, camera(s) to capture images (front and back), a fingerprint sensor, global positioning system (GPS), accelerometer, gyroscope, thermometer, pedometer, heart rate monitor, light sensor, touch screen, and barometer (not to mention the various connectivity technologies such as Wi-Fi, Bluetooth, GSM/CDMA, LTE and NFC).[30]

Crop and livestock management serve as primary areas where connected sensors can provide data and facilitate ease of use for farmers and ranchers dealing with unpredictable climates. Sensor measurements also aid in the detection and prevention of major natural disasters. With pressure, temperature, and weather pattern sensor technology, appropriate emergency preparedness strategies can be used to brief, alert, educate and, if need be, evacuate populations in high-risk areas. Sensors equipped with accelerometer or seismographic capability can warn populations in high-density urban areas of impending earthquakes, tsunamis or typhoons.

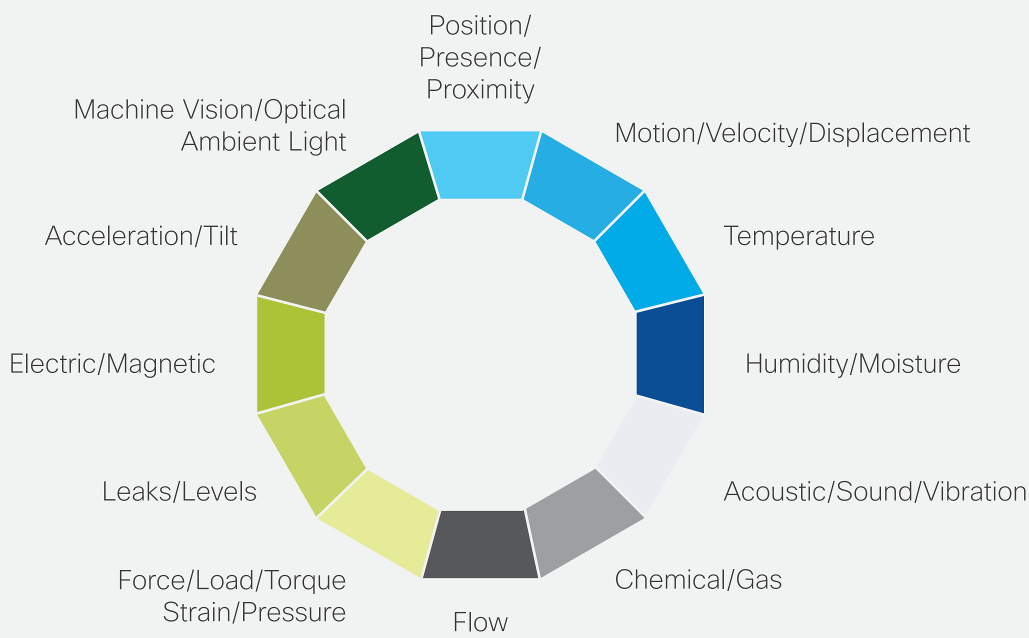
Sensors are one of the primary modes of realizing the full potential of value added to companies, communities, and individuals that employ them for IoT purposes. In general, sensors host a heterogeneous school of functions. They can detect everything from changes in temperature and humidity to the amount of force and pressure being simultaneously applied to thousands of products on a manufacturing floor. Sensors can be broadly deployed to overcome a host of challenges but, in some cases, they may need to be highly customized. It is this customization that enables sensors to provide real added value for IoT and ICT4D initiatives.

Appropriate ICT sensor technologies that address challenges surrounding primary healthcare, agriculture, aquaculture, water treatment, and air quality can be deployed in an efficient and cost-effective manner. Figure 5 (page 19) illustrates some commonly found sensors.

Photo credit: Marco Zennaro. Solar powered air quality sensor in Cotonou, Benin, sending data via SMS.

30 http://www.phonearena.com/news/Did-you-know-how-many-different-kinds-of-sensors-go-inside-a-smartphone_id57885; http://web.stanford.edu/class/cs75n/Sensors.pdf

Figure 5: Range of common sensors



Source: Harbor Insights.

Figure 5 highlights the range of common sensors available on the commercial market, while Table 2 (page 20) segments sensors by example and use case:

- Position, presence, proximity sensors such as the Global Positioning System (GPS) and transponders can provide information about location.
- Motion, velocity, displacement include kinetic sensors that can measure movement, e.g. for wind and water direction, speed, period, precipitation, barometric pressure and motion detection, as well weight measurement (e.g. for animals or loads). Accelerometers measure movement and gyroscopes measure tilt, and digital vernier calipers can measure the size of cracks.
- Temperature sensor measurements are for ambient air or substances, such as water or soil. Similarly, humidity/ moisture can measure the presence of air, water and other substances, including toxic gases.
- Acoustic, sound and vibration sensors can be used to identify wildlife (for research or monitoring) as well man-made noise (including for gunshots, chainsaws and motor vehicles) to aid in anti-logging and anti-poaching efforts.
- Chemical and gas sensors are used to measure oxygen, nitrates, pH, salinity, black carbon and carbon dioxide. Additional types of sensors can measure leaks and levels of fluids and gases, or levels of electricity and magnetism which can provide information about instrumentation such as battery life.
- Flow sensors are used in water pipes, pumps, bodies of water, and air.
- Force/load/torque/strain/pressure sensors can be used for weight measurements as well as in monitoring infrastructure (such as traffic flow over bridges).
- Machine vision and optical ambient light sensors can measure different elements of visual bandwidth (including color, intensity and/or clarity).
- Radiation sensors can measure radiation levels and be used remotely to measure sites for nuclear spills.[31]

31 Interview with John Waugh, April 13, 2015.

Table 2: Sensor Types, Functionality and Examples

Measurement	Functionality	Sensor Examples	Use Cases
Proximity/Position	Detect and respond to angular or linear position of device	RFID, linear position sensors, GPS position sensors, location finding	Land management; natural resource/wildlife management; illegal activity tracking
Motion/Velocity/ Displacement	Detect movement outside of component within sensor range	Ultrasonic proximity, optical reflective sensors, Passive infrared (PIR), inductive proximity, accelerometers, gyroscopes	Emergency preparedness; land management; illegal activity tracking
Weather/Temperature	Detect amount of heat in different mediums and metrics	Thermometers, resistant temperature detectors, thermocouples, infrared thermometers	Water access; water treatment; agriculture; emergency preparedness; land management
Acoustic/Sound/Vibration	Detect decibel level sound or seismic disturbances	Seismography, firearm sensors, commercial security	Emergency preparedness; illegal activity tracking
Flex/Force/Pressure/Load	Detect force(s) being exerted against device	Pressure monitors, capacitive transducers, piezoresistive sensors, strain gauges	Natural resource management
Chemical/Gas/Electric	Detect chemical, gas, or electrical changes in composition of substance	DC/AC electrical current sensors, voltage transducers, smart home sensors, humidity monitoring	Agriculture; natural resource management; health; water treatment
Light/Imaging/Machine Vision	Detect color and light shifts through digital signaling	Real-time temperature monitoring (infrared)	Health

Source: "Roadmap for the Emerging Internet of Things", Carre & Strauss; and Cisco authors' adaptation.

Prototyping feasible IoT solutions is aided by the ubiquity of sensor devices in production and the low cost of entry for users. A complete state-of-the-art IoT sensor suite can be deployed for approximately US$250. In fact, the overall cost of sensor installment, deployment, and support has decreased by a hundred times over the past decade.[32] This low cost of entry makes sensor technology highly accessible to aspiring IoT developers, and enhances innovation in this space. Low-cost sensor technology must be used in tandem with microprocessor and circuit devices.

At a minimum, a single sensor is usually deployed with a single-board micro-controller computer device, such as a Raspberry Pi or Arduino board.[33]

32 https://gigaom.com/2015/01/25/declining-sensor-costs-open-up-new-consumer-applications/

33 http://sweden.nlembassy.org/binaries/content/assets/postenweb/z/zweden/netherlands-embassy-in-stockholm/iot_roadmap_final_draft_0309145.pdf

These micro-controller devices serve as essential IoT purpose-built platforms for the end-user and often require the end-user to be familiar with software engineering principles to achieve effective functionality.

Not all ICT stakeholders need access to full-fledged sensor suites to meet their solutions. Solution-appropriate sensors can be sourced and purchased for US$50-150 depending on the necessary functionality needed to meet various ICT4D challenges, as noted in Figure 6.

Deploying sensors to meet ICT4D solutions can be cost-effective. Realistically, any value gained from utilizing IoT sensor technology could be realized within four to six months post-deployment. For example, a temperature, wind, and precipitation sensor suite in a rural agricultural community could collect and analyze weather data over a three-month timeframe that could be used to better prepare the community for upcoming weather patterns and result in better crop and land management moving forward. It is important to note that the real value from using IoT-enabled sensors derives

Figure 6: Sensors by retail cost

Highest Cost

	Functionality	Sensor Type
$150-$1000+	• Long-term install/deployment • Industrial scale deployment • Extreme accuracy/precision • Typically large enterprises • Ease of solution interoperability	• Chemical/Gas • Electrical/Capacitive • Pressure/Load/Weight • Proximity/Position
$50-$150	• Residential/commercial • Advanced development kits • Consumer-based support • Cloud partnership capability • Fast deployment • Medium infrastructure required • Low-Medium accuracy/Precision	• Water Treatment/Flow • Weather/Temperature • Motion/Velocity • Acoustic/Sound/Vibration • Light/Imaging • Proximity/Position • Flex/Force/Strain
$0 - $50	• Single function • DIY/Prototyping often needed • Limited without other hardware • Requires basic equipment • Geared towards amateurs • Singular functionality • No infrastructure required	• Water Treatment/Flow • Weather/Temperature • Motion/Velocity • Acoustic/Sound/Vibration • Light/Imaging

Lowest Cost

Source: Authors; see annex 3 for further details.

from the ability of experts, analysts, and communities to use their collected data effectively and efficiently to drive current ICT-centered projects and to predict and plan for future challenges that could be addressed with IoT technologies.

Connectivity

The connectivity requirements of different types of IoT networks vary widely, depending on their purpose and resource constraints. A range of different wireless and wireline technologies can be used to provide full IoT connectivity (Figure 7). IoT devices communicate using a range of different communication protocols, which may include: short-range radio protocols (such as ZigBee, Bluetooth and Wi-Fi); mobile networks; or longer-range radio protocols (such as LoRa). These technologies can be segmented based on wireless versus wireline, and the wireless technologies can be grouped by personal area network (WPAN), wireless local area network (WLAN) or wide area network (WWAN) technologies.

Each technology has distinct characteristics, including the range of their signal, the extent of their data throughput (or bandwidth), and the power needs of the communications device (or battery life), among other attributes. Annex 2 discusses these in detail.[34]

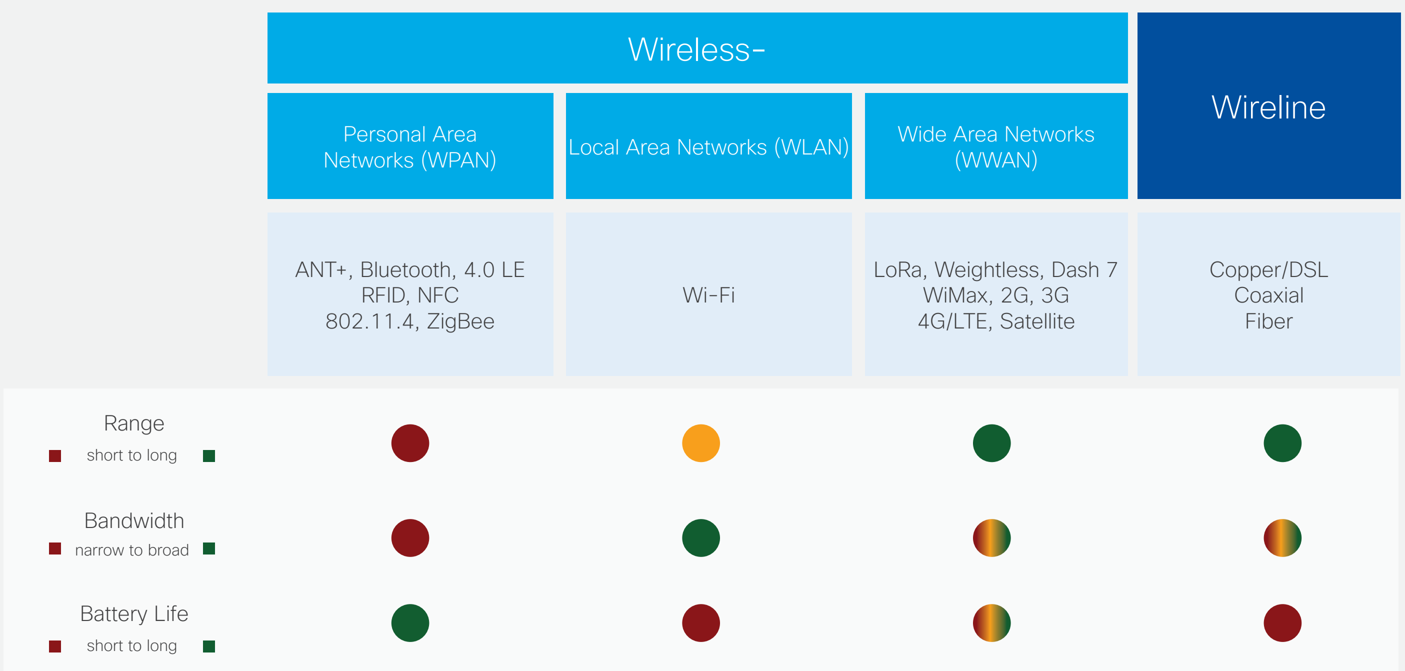
ABI Research notes that technologies such as Bluetooth and ZigBee are helping drive node/sensor implementations, while Wi-Fi or cellular technologies are providing the backbone for data transfer to the cloud.[35] In terms of individual technologies:

- Bluetooth is a high-speed, short-range and high data rate but low battery life wireless technology that can replace wired devices.
- Radio protocols such as Ultra-Narrow Band can provide longer-range coverage (useful for smart city applications such as video monitoring).

34 See also http://www.eejournal.com/archives/articles/20150907-lpwa/

35 https://www.abiresearch.com/market-research/product/1017637-internet-of-everything-market-tracker/

Figure 7: Comparing IoT Connectivity Technologies



Note: Non-exhaustive
Source: Cisco Systems. See also Annex 1.

- Low-rate wireless personal area network (LR-WPAN) is a low-cost, low-power and low data rate wireless technology used for inexpensive mobile devices.
- Devices communicating over kilometres may access the 300 MHz to 3GHz spectrum range;
- Centimetre or millimetre contactless transactions may use Near Field Communications (NFC) in 13 MHz or Extremely High Frequency (EHF) bands.
- Some IoT applications may also make use of AM/FM bands in the Very High Frequency (VHF) range.

Until at least 2010, GSM remained the most widely used technology for M2M,[36] especially in areas with coverage where advanced data transmission had been needed. However, given that many modern multi-sensor networks only require occasional connectivity with minimal throughput and signaling load, GSM connectivity may not be the most appropriate technology for certain projects.

When sensor networks send SMS at regular intervals, costs can accumulate very quickly. Depending on the nature of the sensor network and the terms and conditions of the mobile contract, widespread use of SMS may require negotiation of a separate contract for IoT traffic. For example, in one project in Indonesia, the mobile operator determined that SMS was being used for "business" rather than for "personal" use and changed the fee structure accordingly. There is a risk of bill shock and/or lock-in with a particular provider or providers.

Wi-Fi is a short range wireless technology often used in mobile devices (e.g., PDAs, laptops, tablets, etc.). However, Wi-Fi is playing an increasingly important role in the IoT, with Wi-Fi chips embedded in portable computers and smartphones able to operate on a license-exempt (unlicensed) basis[37] and with the majority of the upgrade costs falling on consumers rather than operators. By 2011, one in ten people were using Wi-Fi, while today, Wi-Fi is in 25% of homes around the world, with two billion Wi-Fi devices sold in 2013.[38]

36 World Bank Broadband Strategies Handbook (2011).

37 The ITU has designated the 2450 MHz and 5800 MHz bands for industrial, scientific, and medical (ISM) applications that "must accept harmful interferences." This is often interpreted to mean that they are considered unregulated. See Frequently asked questions on the ITU-R website. Available at: www.itu.int/ITU-R/terrestrial/faq/index.html#g013.

38 Wi-Fi Alliance. Available at: www.wi-fi.org/organization.php

The FCC's expert IoT Working Group has predicted that IoT will add significant load to existing Wi-Fi and 4G mobile networks.[39] Regulators need to give continuing attention to the availability of spectrum for short-range IoT communications, and the capacity of backhaul networks, as well as encouraging the roll-out of small-cell technology and 4G. Assuming these conditions are met, the Working Group does not expect that new spectrum will need to be explicitly allocated to IoT communications.[40] Cisco observes that spectrum requirements include: narrowband and broadband frequencies; short-haul and long-haul spectrum; continuous data transmission and short bursts of data transmission; and licensed spectrum in addition to license-exempt spectrum.

Ensuring device connectivity and sufficient bandwidth for wireless sensors requires careful planning.[41] It is the combination of these different qualities within Big Data capacity that may offer the most exciting opportunities. For example, location information may be combined with status information to provide real-time information on an evolving situation. There are huge new opportunities opening up by improved access to and use of Big Data techniques, which offer learning opportunities to improve real-world processes and enhance decision-making over the short-to long-term in healthcare, education, emergency services and disaster response.

When integrated into an early warning system, real-time data can be used to forecast potential outbreaks of violence or natural disaster. Text analysis of social media data has the potential to reflect growing tensions in a region given high unemployment or political frustrations.[42] Light emission data collected via satellite-produced remote sensing images can also be analyzed to estimate a country's GDP in real-time.[43]

39 US FCC Technological Advisory Council IoT Working Group, Spectrum: Initial Findings, FCC TAC meeting update, 10 June 2014. Available at: http://transition.fcc.gov/bureaus/oet/tac/tacdocs/meeting61014/TACmeetingslides6-10-14.pdf

40 US FCC Technological Advisory Council IoT Working Group, Spectrum: Initial Findings, FCC TAC meeting update, 10 June 2014. Available at: http://transition.fcc.gov/bureaus/oet/tac/tacdocs/meeting61014/TACmeetingslides6-10-14.pdf

41 Pepper, R. & Garrity, J. (2014) The Internet of Everything: How the Network Unleashes the Benefits of Big Data. Global IT Report 2014. WEF. http://www3.weforum.org/docs/GITR/2014/GITR_Chapter1.2_2014.pdf

42 http://www.unglobalpulse.org/projects/can-social-media-mining-add-depth-unemployment-statistics

43 ITU (2014). "Measuring the Information Society."

Applications across Different Sectors in Development

Photo credit: Juozas Cernius/American Red Cross.
The photograph shows the installation of a smart home sensor network for fire detection in informal settlements in Nairobi, Kenya.

The Internet of Things in a Developing Country Context

This section examines deployments of IoT technologies in developing economies, covering what has worked and formulating summary conclusions on key issues to consider when extending the IoT to the billions of people living in the developing world. The following specific considerations may apply:

1. Increasingly observed in developing countries, more of the population has access to basic telecommunication network coverage than has access to fundamental services such as electricity, running water and basic sewage facilities. The ITU estimates that, in 2015, over 95% of the world's population resides within the coverage area of a 2G mobile-cellular network (and 69% under a 3G network).[1] Figure 8 (page 26) compares and contrasts urban and rural areas in sub-Saharan Africa by their access to electricity, water and mobile coverage.

2. Economic sectors and processes in developing countries are more labor-intensive and may lack supporting processes (e.g. agricultural systems may not use technology-driven crop management, pest/disease control or quality management systems).[2] The Macrothink Institute notes that the information requirements of productive systems in developing countries are likely to be very different from those in developed countries, meaning that monitoring systems for developing countries are likely to need different design requirements and technological frameworks.[3]

3. Lack of resources means that simpler, more cost-effective solutions may prove more effective in a developing country context. For example, using a wireless wide area network – WWAN – for communication could lower the cost of M2M modules by using white space spectrum rather than other networks with high-speed capabilities, according to the GSMA,[4] in areas where there is low interference from analogue broadcasting channels.

4. Connectivity may begin with essential applications only, which could be introduced initially on a small scale and might not always become fully integrated (e.g. as suggested by 'greenshoots' isolated pilots in eHealth and mHealth).

5. More constrained resources and fragile environments may make populations in developing countries inherently more vulnerable to natural disasters. For example, the Red Cross believes "emerging technologies will play a particularly important role in amplifying efforts to facilitate community-level knowledge and health, connection, organization, economic opportunities, access to infrastructure and services, and management of natural resources", and has convened a Global Dialogue on Emerging Technology for Emerging Needs of general relevance.[5]

This does not mean that the developing world lacks the prospects or potential to develop great applications itself — just that deployments may differ from developed country contexts in their purpose, resilience or supporting infrastructures. In developing countries, for example, deployments may be more likely to be made in isolation and independent of supporting infrastucture. The much-cited application of M-Pesa introduced by Safaricom in Kenya began essentially for unbanked consumers, compared with the development of wireless payment systems in industrialized countries, where mobile money transfers may accompany or complement the formal banking system.

Fixed-line infrastructure is also often more prevalent in developed country contexts, where IoT applications can run off high-capacity fixed line infrastructure, compared to developing countries, where IoT or sensor networks

1 "ITU Facts and Figures – The World in 2015." Available at: www.itu.int/en/ITU-D/Statistics/Pages/facts/default.aspx

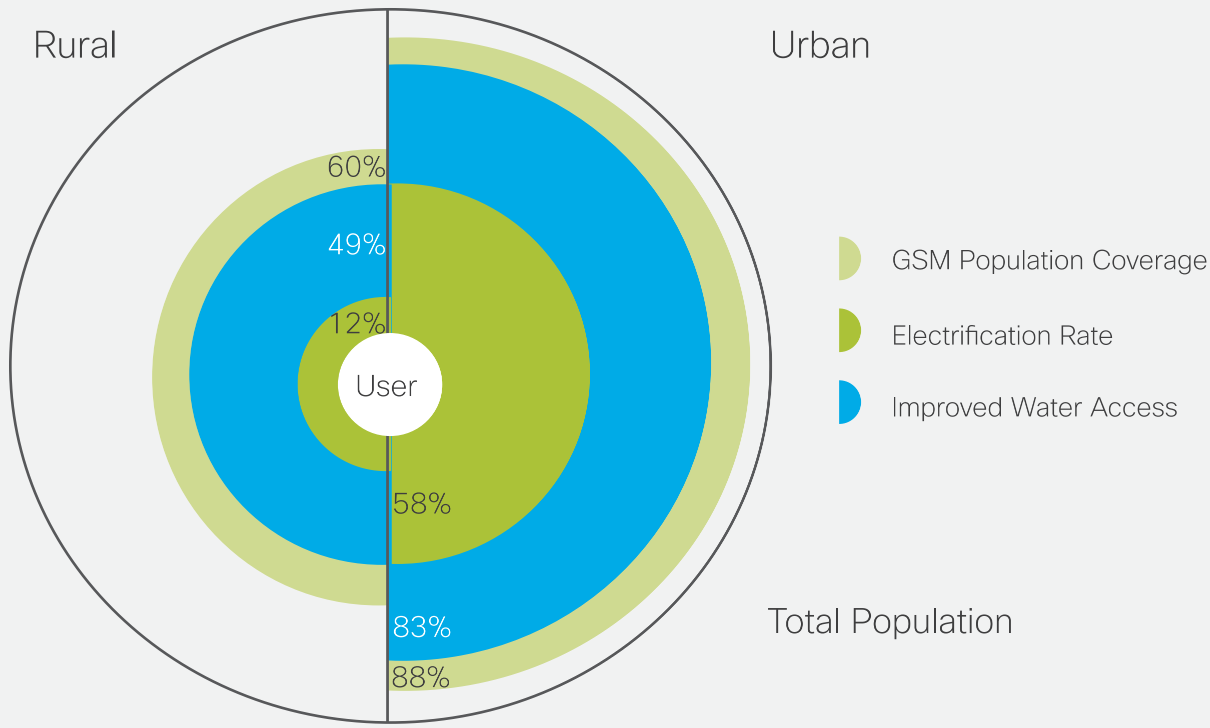
2 Karim, Anpalagan, Nasser & Almhana (2013). "Sensor-based M2M Agriculture Monitoring Systems for Developing Countries: State and Challenges." Macrothink Institute.

3 See Footnote 2.

4 http://www.gsma.com/mobilefordevelopment/wp-content/uploads/2013/01/Sustainable-Energy-and-Water-Access-through-M2M-Connectivity.pdf

5 "A Vision for the Humanitarian Use of Emerging Technology for Emerging Needs: Strengthening Urban Resilience." Available at: https://drive.google.com/file/d/0B1vf6TLGlC0yZk9UU2t2UGFmNlE/view?pli=1

Figure 8: Access to Energy, Water & GSM Population Coverage in Sub-Saharan Africa



Source: GSMA, "Sustainable Energy & Water Access through M2M Connectivity. http://www.gsma.com/mobilefordevelopment/wp-content/uploads/2013/01/Sustainable-Energy-and-Water-Access-through-M2M-Connectivity.pdf.

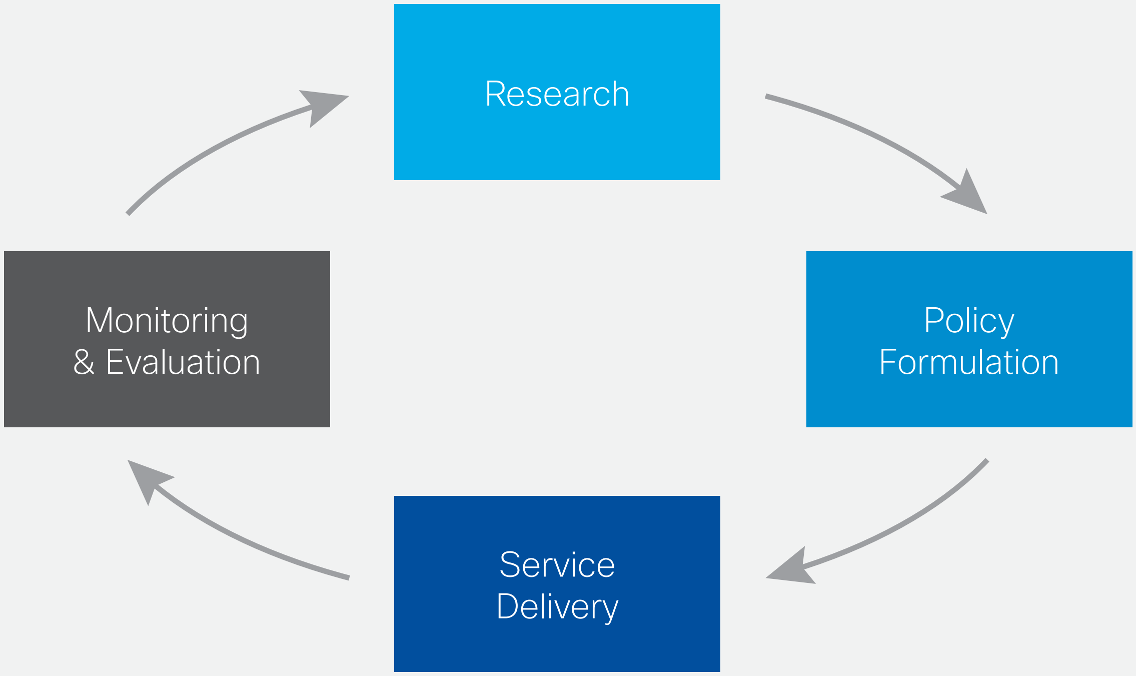
are most likely to be used in conjunction with mobile infrastructure.

IoT interventions are increasingly common in advanced economies. Wearable sensors in watches, bracelets and even clothes can help users monitor their vital signs and improve their health and wellbeing. In homes, offices and factories, sensors can detect when rooms are in and out of use, enabling more efficient heating and lighting and helping improve working conditions. In many more environments, smart meters can coordinate the energy consumption of appliances to smooth out variations in overall energy consumption and achieve more effective use of variable renewable energy sources.

In developing country contexts, a range of uses and applications of IoT technologies first started to appear a decade ago. Impactful IoT interventions in development either improve efficiency (achieving similar levels of impact with fewer resources) or effectiveness (increasing impact with similar levels of resources).[6] IoT applications could help promote monitoring and evaluation, and achievement of nearly all the existing Millennium Development Goals (MDGs) and post-2015 Sustainable Development Goals (SDGs) (Table 3, pages 39-40). For example, sensors in agricultural fields are monitoring soil conditions and moisture levels. RFID tags are helping farmers provide more personalized

6 James Bon Tempo. Available at: http://linearityofexpectation.blogspot.com/2015/02/the-purpose-of-ict4d-in-one-diagram.html

Figure 9: The Virtuous Circle of Development Impact



Source: Cisco Systems.

care for their livestock. Connected thermometers are monitoring vaccine delivery and storage in real-time. Cameras and sensors in smartphones and tablets are allowing healthcare workers to provide remote diagnosis of disease. And off-grid solar systems, monitored via SMS, are bringing affordable electricity to lower income families.

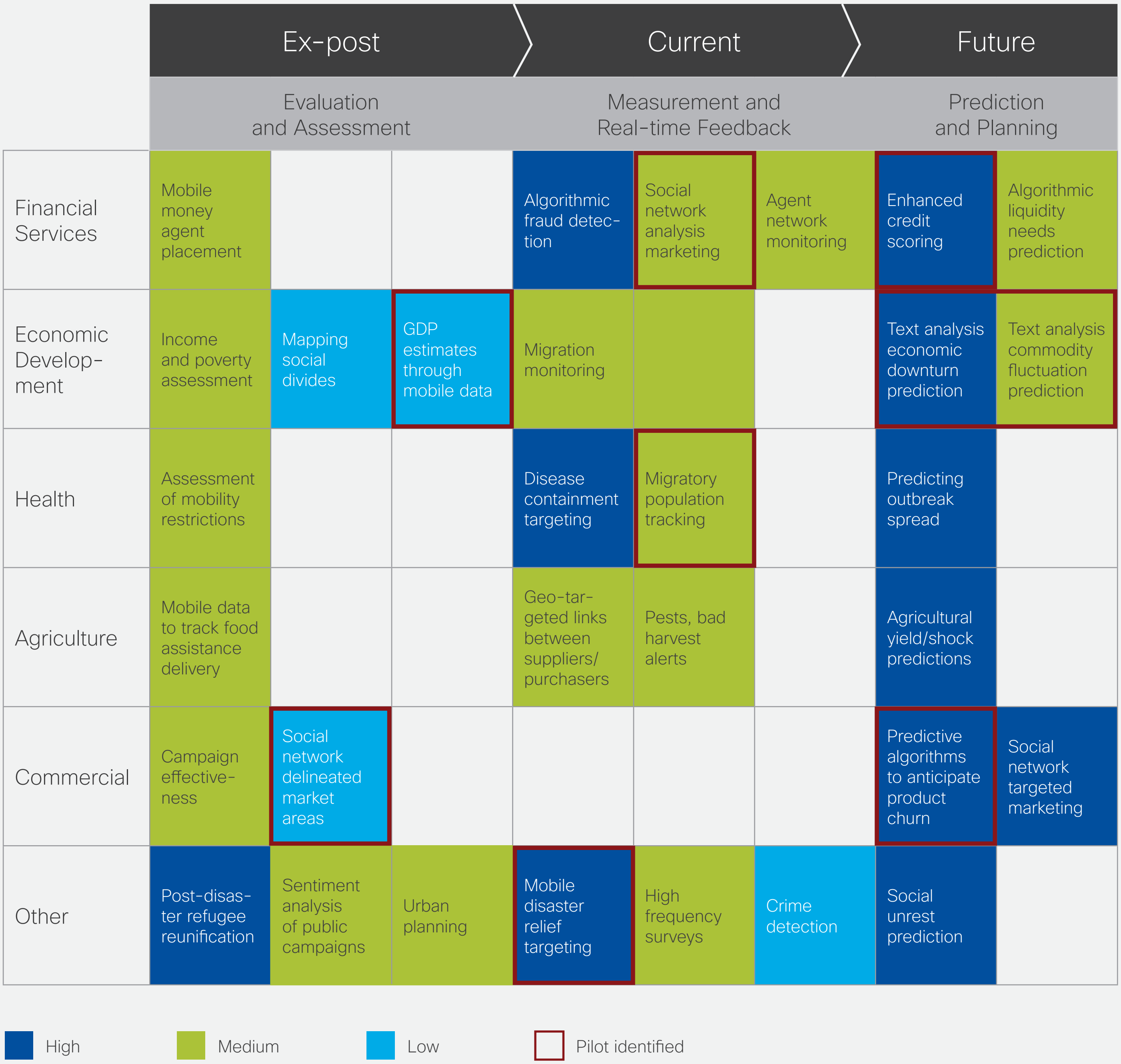
In tackling global development challenges, IoT interventions are being utilized across the full spectrum of development activities (Figure 9). Figure 10 (page 28) highlights how Big Data capacities enable both real-time monitoring and response, and also predictive pattern data analysis, facilitating a shift in strategy from reactive to proactive. Academic researchers are deploying sensors to improve research on increasing agricultural yields, for example. Public policy is being informed by data collection on community water usage.

Healthcare

The IoT has the potential to improve health and wellbeing through greater efficiency and improved care in existing healthcare settings, by enabling greater use of remote telehealth provision, and enabling individuals to monitor their own health day-to-day, improve wellbeing and better manage conditions (such as stress, encouraging exercise and healthy eating), diagnose medical conditions more quickly and promote treatment regimes.

In terms of preventative care, IoT fitness devices such as Fitbits, and movement sensors now built into many new smartphones, enable many individuals to monitor and track themselves, which generally promotes healthier lifestyles. For example, Apple and Google have added features to their latest smartphone operating systems to integrate health sensor devices and promote users to monitor their own health data using non-specialist health tracking apps.

Figure 10: Areas of Highest Potential Impact across Different Sectors



Source: Naef et al. (2014), quoted in the “Measuring the Information Society 2014” report, ITU.

As for chronic conditions, people with type 1 diabetes may soon be able to set their insulin doses by smartphone. Researchers are testing a "bionic pancreas" pump that is inserted under the patient's skin. When paired with an app and a small chip, this device is capable of tracking blood sugar levels and adjusting the amount of insulin and glucagon (another hormone that controls blood sugar) on its own. A key study is slated for 2016 and the researchers, who are based at Boston University and Massachusetts General Hospital, plan to submit the device for US FDA approval in 2017.[7]

In developing countries, one innovative way sensors are being used is to monitor the 'cold chain' delivery of vaccines, particularly to remote and rural areas. Nearly one-fifth of children in the developing world go unvaccinated each year. One of the contributing factors to this problem and a large hurdle for healthcare providers is vaccine spoilage, as many vaccines need to be stored at temperatures between 2 and 8 degrees Celsius. With over 200,000 vaccine refrigerators in use in the developing world alone, most of them in harsh and remote environments, keeping the cold chain up and running is a major challenge.

A number of projects have focused on monitoring the cold chain, and one organization in particular, NexLeaf, has been working on remote sensing products for use in difficult environments.[8] In many countries, refrigerator temperatures are tracked and recorded by hand, often with delays in collecting the records. Now, using IoT technologies, remote sensors monitor and record the refrigerator temperatures and send out SMS alert messages whenever there is a problem (i.e., when temperatures rise above a predetermined threshold). Nexleaf has developed a mobile-enabled thermometer that sends regular messages to recipients regarding current temperatures, and also warnings when the temperature begins to approach critical thresholds.

Cellular networks are being used to transmit this data due to their relatively low costs. For example, in India, monthly cellular connectivity for connected thermometer solutions are in the range of around a dollar a month or less per fridge. The most expensive component is often the cell radio, while conversely, the temperature sensors are relatively cheap. In some cases, advantageous mobile cellular terms can be negotiated, resulting in reduced operating costs. Messages are sent to a web site and then automatically relayed to service technicians. A daily summary of refrigerator temperatures is also sent to the website, so managers can understand how well equipment is functioning.

This data can be used at the local and district level, as well as being aggregated up to or by the Ministry of Health at the national level to determine how much capacity is available, and where vaccines may best be distributed in response to an outbreak or epidemic. Big Data can be used to help understand where and when problems are arising in power supply, equipment breaking down, management issues, and how best to resolve these challenges. These data can be integrated to manage and improve the supply chain. Another example of these types of interventions is the SmartConnect project, which focused on developing a "communication appliance" to improve the reliability and performance of the "cold chain."[9]

IoT technologies are also being used to address immediate challenges in humanitarian response, such as the Ebola outbreak in West Africa. The United States Agency for International Development (USAID) has supported and employed IoT solutions via connected wearable technologies. Sensor Technology and Analytics to Monitor, Predict, and Protect Ebola Patients (or STAMP2 for short) has been tested on Ebola patients in the United States and is being scaled up to meet the needs of government agencies such as USAID for its Ebola treatment strategy in Liberia.

STAMP2 collects patient data, including ECG, heart rate, oxygen saturation, body temperature, respiratory rate, and position. These data are sent to a central server or

7 www.webmd.com/news/breaking-news/future-of-health/default.htm#wireless-medicine-toc/wireless-medicine

8 Interview with Nexleaf on March 23, 2015. http://www.nexleaf.org

9 http://homes.cs.washington.edu/~eorourke/papers/smart_connect_nsdr.pdf

platform so they can be monitored and analyzed over a long period of time and alert physicians of abnormal changes in a patient's behavior or health. The STAMP2 sensor will be deployed in Ebola-stricken areas using a connected health patch, or "Smart Band-Aid." The fully equipped sensor-enabled band-aid is estimated to cost approximately US$100 with a maximum battery life of ten days, making it ideal for use in field-based Ebola treatment centers. Deploying solutions such as the STAMP2 sensor can improve the Ebola response initiative at-large by decreasing emergency response time in critical areas and enabling emergency responders to detect Ebola patients earlier and monitor them more efficiently.[10] Other examples include the use of remote diagnostics systems that allow for community health workers to take measurements from patients and transmit the data to doctors or specialists elsewhere.[11]

10 http://mobihealthnews.com/40564/scripps-wins-usaid-grant-to-monitor-ebola-patients-with-medical-wearables/ and http://www.biospectrumasia.com/biospectrum/news/220757/usaid-unveils-wearable-technologies-tackle-ebola

11 http://www.ictworks.org/2015/07/31/5-mhealth-innovations-using-mobile-phone-extensions-and-wearables

Water and Sanitation

Nearly one billion people in the world lack access to safe drinking water, while some two billion have inadequate access to sanitation facilities. Currently, some of the most extensive uses of the IoT in developing countries are in projects where the objectives include the improvement of clean water delivery and/or sanitation.

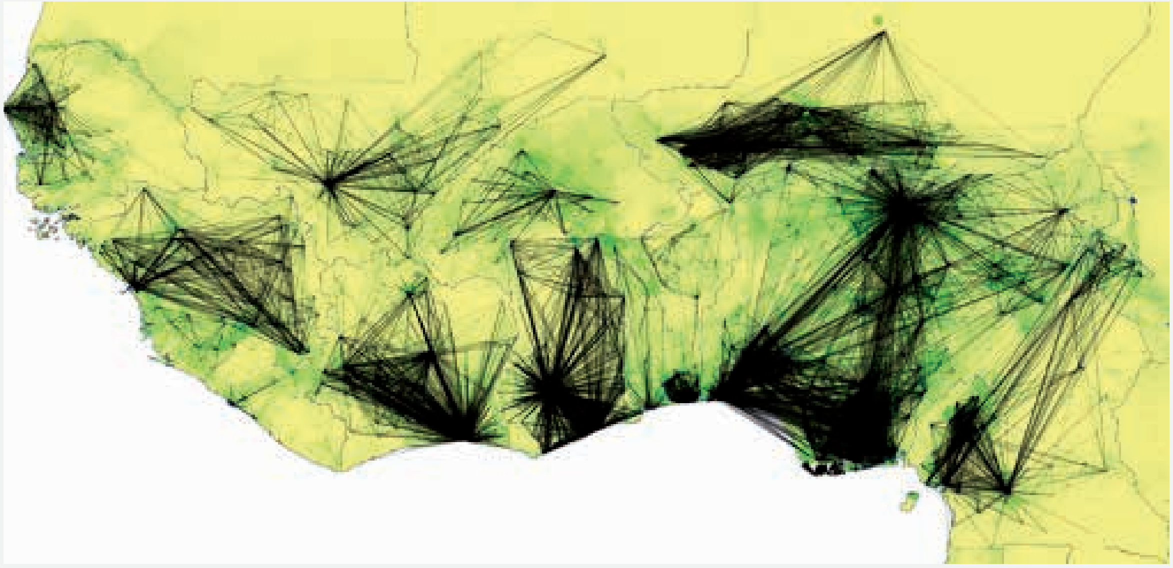
In Bangladesh, a biosensor network of 48 manual arsenic sensors is being used to monitor water quality.[12] In Jiangsu, China, water supply is being monitored by adding IoT sensor devices at key points to register data on water usage and flow rates.[13] In India, Sarvajal has developed low-cost reverse osmosis technology to provide clean water in rural areas, as well as smart meters to remotely monitor the quality and quantity of water. Additionally, a wireless sensor network (WSN) is being used in the country to improve water management

12 http://users.ictp.it/~mzennaro/WSN4D.pdf

13 www.chinamobileltd.com/en/ir/reports/ar2010/sd2010.pdf

Figure 11: Monitoring the Movements of People during the Ebola Outbreak

The figure shows regional travel patterns in West Africa based on mobile phone data and demonstrates how anonymized call detail records (CDRs) can inform healthcare response activity in the event of an outbreak of infectious disease, such as Ebola.



Source: http://eprints.soton.ac.uk/370053/1/CommentaryEbolaOutbreak.pdf

Photo credit: Tim Foster, Rob Hope, Johanna Koehler and Patrick Thomson. Sensor enabled village hand water pump in Kyuso District, Kenya.

in poor and semi-arid areas. The wireless COMMON-Sense Net has been deployed over a small area of two acres to measure temperature, humidity, ambient light, and barometric pressure in rural Karnataka. Soil moisture has been measured with a special probe since April 2005.[14] Data from the sensors are visualized on the project's website for real-time monitoring.

In Africa, water service reliability is closely correlated with extreme poverty and water insecurity in rural areas. Around one million hand pumps supply water to over 200 million rural water users across the continent, yet as many as one third of all hand pumps are thought to be broken at any given time, with 30-70% of pumps breaking within two years. The Smith School Water Programme at Oxford University launched a 12-month 'smart hand pump' trial in Kyuso, Kenya, in 2013 in an attempt to resolve problems related to broken water pumps and to test a new maintenance model for universal and reliable water services.[15]

14 http://itidjournal.org/itid/article/viewFile/244/114
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4085509

15 www.smithschool.ox.ac.uk/library/reports/SSEE_Rights%20to%20Results_FINAL_March2014.pdf

Using a basic accelerometer, similar to that found in a mobile phone, to capture movement of the pump handle, the team developed a robust transmitter which fits into the handle of existing hand pumps, opting for "field readiness" over technological sophistication (e.g. using SMS rather than 3G to transmit data), as their need for more robust, reliable data outweighed that for data with advanced functionality. The team opted for non-rechargeable batteries, with a replacement lifetime longer than the pump maintenance cycle. An advantageous mobile package and efficient use of the SMS message format has resulted in relatively affordable data costs.

From the initial question of whether the pump was working or not, the team quickly realized that they could remotely monitor a host of data relating to water supply and demand, including hourly flow rates, usage data, hand pump performance, seasonality, and peak periods for demand. Based on these data, a more evidence-based approach to policy decision-making has been achieved. It is no longer the village that "shouts loudest" or that has the best social connections that ultimately receives service. The project has been able to provide evidence about where and when the greatest needs for water are experienced.

The team emphasizes that the project has led to a shift in mindset. Although the Kenyan water regulator had an existing mandate for regulating water supply in rural areas, it was not able to engage effectively, as it lacked concrete data about the situation. Now that more data are forthcoming, the water regulator is better able to manage resources. Performance-related pay has also been introduced for maintenance staff, who now know that pumps are being monitored remotely, and who are generally more keenly engaged and responsive in repairing pumps.

Although project staff were initially worried about vandalization of the equipment, once people saw that the technology worked and that it contributed to the pump being repaired more quickly, local social structures of respect and trust extended to include and protect the transmitter. Due to these factors, over its lifetime, this project has helped achieve:

- a ten-fold reduction in hand pump downtime (measured by the number of non-functional days);

- a shift to 98% of hand-pumps functioning (up from 67%);
- a more fair and flexible payment model contingent upon service delivery; and
- new and objective metrics to guide water service regulatory reform.

MoMo is a similar, but fully mobile, device with a sensor that collects data to track infrastructure and improve accountability in the developing world. The device identifies where pumps are broken and alerts repair teams to fix them. Data from MoMos can also help communities monitor the effects of infrastructure projects and inform future investments.[16]

In Rwanda, SWEETSense uses sensor technology developed by Portland State University's SWEETLab (Sustainable Water, Energy & Environmental Technologies Laboratory) to monitor pump performance and water flow, notifying technicians via SMS and emails.[17] SWEETSense technology uses sensors to provide continuous data on usage and performance of programmes in water, sanitation, household energy and rural infrastructure programmes with diverse partners including USAID, the UK's DFID, Mercy Corps, the Lemelson Foundation, Gates Foundation and DelAgua Health in India, Nepal, Indonesia, Kenya, Rwanda and Haiti. Indeed, SWEETSense technology has been used for:

- Water pumps in Kenya;
- Cooking stoves in India;
- Latrine monitoring in Bangladesh; and
- Water filters for hand-washing stations in Indonesia.

These sensors use Wi-Fi or cellular via GSM using a local SIM card (in East Africa, Airtel or MTN or Safaricom offer data plans for around US$6-10 a month to transmit data). The data is then integrated into SWEETData™, an Internet database monitoring summary statistics on performance and usage to front-end users. Sensors currently cost more than US$100, but this should fall relatively quickly, as demand increases.

16 Interview with WellDone.org/ Momo on March 24, 2015. https://www.welldone.org/

17 http://newsroom.cisco.com/feature/1556125/Sensors-Change-Lives-in-Developing-Countries

For order/manufacture volumes of several hundred thousands of sensors at a time, price reductions can begin to be realized, which will help boost scale.

In Rwanda, sensors may add 10% to the cost of a hand pump but may enable uptime to increase by some 80-90%, significantly reducing the cost per unit of water per 10,000 litres delivered. Sensors are subjected to very harsh conditions, typically resulting in some 12-18 months of battery life. In Kenya and Rwanda, the regulatory challenges have proven relatively limited so far, and the regulations for large-scale connectivity are nascent.

Water flow sensors are also being used in sanitation projects focused behavior change. For example, in one water, sanitation, and hygiene programme in Indonesia, flow sensors were combined with motion detectors to measure the impact of behavior change training, with the aim of increasing hygienic actions (i.e., washing hands after latrine use). The study found community participants were washing hands after latrine usage, but that the survey responses (those who indicated they wash their hands after using the latrine) were significantly higher than the data captured by the motion sensors, suggesting that over-reporting had occurred in the verbal and self-reported surveys.[18] Similar techniques can be used to remind staff of basic hygiene techniques in homes, clinics, and hospitals.

Agriculture

In agriculture, IoT technologies can be used to increase, protect, and optimize crop production, as well as improve the storage and distribution of food. Growth in agricultural productivity over the last fifty years has been much slower in developing regions of the world, in part due to large capital costs.[19] Similarly, gathering and utilizing local weather data, a critical aspect of farming, remains a major challenge in developing regions due to limited coverage. Traditional weather monitoring equipment is large and capital-intensive, but the IoT is now allowing

18 Evan Thomas; Kay Mattson 2014. Instrumented Monitoring with Traditional Public Health Evaluation Methods. Available at: http://www.mercycorps.org/sites/default/files/Instrumented%20Monitoring%20Indonesia.pdf

19 http://www.economist.com/news/middle-east-and-africa/21665005-small-farmers-africa-need-produce-more-happily-easier-it

for micro-weather stations to be deployed and utilized for a range of activities, including the dissemination of information to farmers on nutrient requirements, the prediction of weather patterns, and the provision of inputs into localized crop insurance schemes.

For example, Syngenta's Kilimo Salama ("Safe Farming") project is a connected weather station that monitors agricultural events and facilitates linkages with insurance firms. The aim is to mitigate the risks associated with adverse weather, thereby providing a much-needed safety net for farmers while promoting agricultural investment and improved livelihoods. Safaricom's M-Pesa mobile banking system assists Kilimo Salama in keeping index insurance premiums more affordable, helping transform smallholder farmers into a commercially viable market segment for insurance firms.[20]

Various types of micro-weather stations capture a range of data such as air and soil temperatures (ºC and ºF), air and soil moisture levels (%), solar radiation (W/m2), wind direction, wind speed (m/s), atmospheric pressure (hPa), amount of rainfall (mm), soil electrical conductivity (EC, 0-23dS/m), and visual appearance (image capture). At the end of each growing season, weather statistics collected from solar-powered weather stations are automatically compared with an index of historical weather data. Rainfall measurements are factored into specialized agronomic models to determine the impact and likely loss that farmers experience. Insurance payouts are then calculated and sent to the insured farmers via automated mobile payments. This mechanism has effectively automated and simplified the claims process, cultivating a financially supportive environment for individual farmers and encouraging agricultural production at all levels.

In India, Nano Ganesh is a low-cost solution to provide small-shareholder farmers with a tool that can remotely control their micro irrigation pumps.[21] Across the country, about 25 million water pumps are in use for farm irrigation. Many of these pumps have to be manually operated, based on rainwater conditions, electricity availability and crop needs. For the average small-scale farmer, the variability of these factors on a day-to-day basis adds extra burdens in terms of time, labor and fuel costs. In many cases, farmers need to travel long distances through difficult conditions to access their pumps from their households.

The Nano Ganesh unit works by attaching to the irrigation pump, and serving as an actuator which can turn the pump on and off via basic commands from a farmer's simple feature phone (2G mobile telephones). The farmer is also able to check the availability of electricity at the pump, as well as the availability of water near the pump (with an additional water sensor). By August 2014, around twenty thousand farmers in India had benefitted from Nano Ganesh.

China is making great strides in applying IoT technologies to improve agricultural production. Various information-based applications have been developed, including greenhouse remote monitoring, automatic drip irrigation, and milk source safety information management to enhance agricultural production. In Xinjiang, the "mobile Internet of Things for Agriculture" project uses wireless monitoring of agricultural greenhouses. Wireless water-saving drip irrigation has also been used since 2011 to monitor water quality and to save water in fresh water aquaculture.[22]

Additional examples include the use of RFID tags for monitoring livestock, which allows for more personalized care for individual animals. In tea plantations in Sri Lanka and Rwanda, WSNs are being utilized to monitor soil moisture, as well as carbon, nitrogen, potassium, calcium, magnesium, and pH levels. The sensors and connectivity modules are powered through solar panels, and the data are transmitted wirelessly.[23]

20 "The Broadband Effect: Enhancing Market-based Solutions for the Base of the Pyramid." Available at: https://publications.iadb.org/bitstream/handle/11319/6642/Opportunities_for_the_Majority_Report_The_Broadband_Effect.pdf.pdf?sequence=1

21 Food and Agriculture Organization of the United Nations, "Success Stories on Information and Communication Technologies for Agriculture and Rural Development." Available at: http://www.fao.org/3/a-i4622e.pdf

22 http://www.chinamobileltd.com/en/ir/reports/ar2010/sd2010.pdf
http://newsroom.hwtrek.com/?p=626

23 Minuri Rajapaksa "IoT for Productive Tea Plantation." Available at: http://wireless.ictp.it/school_2015/presentations/CaseStudies/IoTforTeaPlantation-SriLanka-Minuri.pdf
http://wireless.ictp.it/rwanda_2015/
http://www.ictp.it/about-ictp/media-centre/news/2015/6/teatime-with-iot.aspx

Resiliency, Climate Change, and Pollution Mitigation

Following the 2004 Indian Ocean tsunami that devastated coastal areas in India, Sri Lanka, Thailand and Indonesia, the international community united to establish the Indian Ocean Tsunami Warning System whereby kinetic sensors (measuring waves and water flow) placed on the ocean floor communicate data on potential tsunamis to disk buoys floating on the ocean surface via acoustic telemetry. The buoys then upload the information to government authorities via satellite connectivity.[24] The ITU has launched a project to detect earthquakes and seismic events via a network of sensors hosted on submarine cables.

Other applications designed to promote resiliency include a Red Cross project to explore the widespread installation of connected alarm systems across high density urban slums to quickly notify residents of fast-moving fires. Fires can move quickly in informal settlements and slum areas, given that homes are close in proximity. Faulty wiring and indoor open hearths, when combined with the density of these settlements, make combating fires quite difficult, and, unfortunately, more likely to start. The Red Cross is exploring the development of low-cost, solar-powered sensors networked together to quickly detect and relay to authorities when fires emerge. The network sounds alarms, communicates to threatened residents (via SMS and other modalities), and its connected sensors identify via GPS where the fire has started, notifying authorities of the location where fire mitigation efforts should be targeted.[25] Currently, the intervention is being tested in Nairobi and Cape Town, with participation by two thousand households.

Many analyses are now trying to model risks and vulnerabilities in the wake of climate change. For example, climate models and disaster risk models can now be combined with satellite imagery of human settlement (such as night-time lights) to estimate economic exposure to risk.[26] New sensor data also include unmanned aerial vehicles ("drones") and spatially referenced (geo-referenced) video.

Geo-referenced video has been used to quickly identify sites of standing sewage and water to aid in cholera risk mapping in Haiti [27] and the vulnerability of homes in Los Angeles, to wildfire.[28] Drones can provide very high-resolution (VHR) satellite imagery in 2-D and 3-D, which can be useful in mapping complex urban riverine topography, and which has been used in Haiti for flood

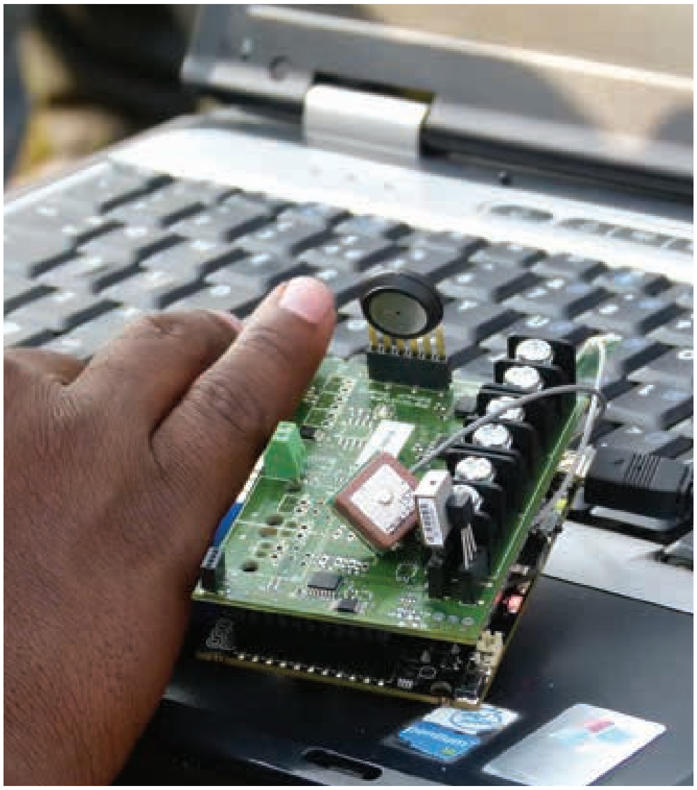


Photo credit: Marco Zennaro. Calibration of a sensor node measuring weather parameters (temperatures, pressure, humidity, light) in Nairobi, Kenya.

24 http://www.kophuket.com/phuket/homemenu/tsunami.html and https://en.wikipedia.org/wiki/Indian_Ocean_Tsunami_Warning_System

25 https://drive.google.com/file/d/0B1vf6TLGlC0yZk9UU2t2UGFmNlE/view?usp=sharing

26 Ceola, S., Laio, F., & Montanari, A. (2014). Satellite night-time lights reveal increasing human exposure to floods worldwide, 7184–7190. doi:10.1002/2014GL061859. Received; and Christenson, E., Elliott, M., Banerjee, O., Hamrick, L., & Bartram, J. (2014). Climate-related hazards: a method for global assessment of urban and rural population exposure to cyclones, droughts, and floods. International Journal of Environmental Research and Public Health, 11(2), 2169–92. doi:10.3390/ijerph110202169

27 Blackburn, J. K., Diamond, U., Kracalik, I. T., Widmer, J., Brown, W., Morrissey, B. D., … Morris, J. G. (2014). Household-Level Spatiotemporal Patterns of Incidence of Cholera, Haiti, 2011. Emerging Infectious Diseases, 20(9), 1516–1520.

28 Burkett, B., & Curtis, A. (2011). Classifying Wildfire Risk at the Building Scale in the Wildland-Urban Interface: Applying Spatial Video Approaches to Los Angeles County. Risk, Hazards & Crisis in Public Policy, 2(4), 1–20. doi:10.2202/1944-4079.1093

modelling, as well as in Nepal after the destructive 2015 earthquake.[29]

New datasets can help in understanding vulnerability and mobility, and data to estimate mobility patterns can be gleaned for example from geo-located tweets. One researcher analyzed New York City tweeters before, during, and after Superstorm Sandy to show that pre-disaster mobility patterns can indicate the potential range of mobility during a disaster.[30] Other indicators of mobility include transit data by bikes,[31] buses and subways being made available by hundreds of municipalities.[32] Transit data can monitor population flux at different times of day, and provides just one example of open data which cities are releasing that could be valuable for risk assessment.

Population movement analyses based on Call Detail Records (CDRs) from mobile network operators have also been used for planning malaria elimination strategies and, more recently, to monitor population movements in the 2014 Ebola outbreak in Guinea, Sierra Leone, Liberia, Nigeria and Senegal. Despite some initial challenges, epidemiological models of the spatial spread of Ebola were developed to model the spread of the virus, and predict its possible development (Figure 11, page 30). These models can help assess the likely routes of infected individuals between populations, predict possible new outbreaks and help focus the delivery of eventual vaccines. However, challenges remain in terms of establishing the processes by which such data can be shared and released in a timely fashion.[33]

Additionally, privacy issues still need to be addressed, such as the right level of anonymity (and aggregation, such as from the individual to a group level) for records to ensure an appropriate balance is struck between ensuring individual privacy, while preserving the value of the data for social aims (including crisis response and policy planning).[34]

Urban air pollution is a major problem in many developing country cities. The World Health Organization (WHO) suggests that polluted air contributes to one in eight deaths worldwide, as dirty air causes lung damage, heart disease, strokes and cancer. The WHO also estimates that indoor air pollution in homes in Africa contributed to nearly 600,000 deaths in 2012.[35] To measure the extent of the problem, air quality sensors are being deployed in a range of cities to track levels and changes in pollutants. One such project, "Fresh Air in Benin" is focused on developing a network of air quality sensors to capture and send data every 20 minutes via GSM connectivity.[36]

Water flow sensors are also being used to help collect hydrological data in developing countries where local data on river flow and levels may not be regularly collected. These sensors can also provide early warning of floods. For example, the Hidrosónico is a water stream gauge that uses a sonar range sensor to measure the distance to water surface level. The module sends the readings on a regular basis to recipients (via SMS or email) or to a cloud application. The unit is also equipped with a rain gauge to monitor precipitation, and is currently deployed in Honduras.[37]

29 Big Data in the Disaster Cycle: Overview of use of big data and satellite imaging in monitoring risk and impact of disasters; Tellman, Schwarz, Burns, Adams

30 Wang, Q., & Taylor, J. E. (2014). Quantifying Human Mobility Perturbation and Resilience in Natural Disasters. arXiv.org, physics.so(11), 1987. doi:10.1371/journal.pone.0112608

31 Zaltz Austwick, M., O'Brien, O., Strano, E., & Viana, M. (2013). " The structure of spatial networks and communities in bicycle sharing systems. PloS One, 8(9), e74685. doi:10.1371/journal.pone.0074685

32 https://code.google.com/p/googletransitdatafeed/wiki/PublicFeeds for a list

33 http://www.economist.com/news/science-and-technology/21627557-mobile-phone-records-would-help-combat-ebola-epidemic-getting-look

34 http://www.unglobalpulse.org/projects/mobile-data-privacy

35 http://www.nytimes.com/2014/04/17/business/energy-environment/measuring-africas-air-pollution.html

36 http://www.worldbank.org/content/dam/Worldbank/Feature%20Story/Makers4development.FV%20USAID.pdf

37 http://dai.com/our-work/solutions/dai-maker-lab and https://github.com/DAI-Maker-Lab/hidrosonico

Natural Resource Management

Protecting land and the environment from pollution and illegal logging, as well as protecting natural wildlife from poaching, are major natural resource challenges in developing countries. One example of a working prototype drone has been developed to help monitor wildlife in remote and mountainous areas in the United Arab Emirates (UAE). Camera traps take automatic photos of animals, triggered by motion. However, reaching the camera traps is dangerous and costly and it is time-consuming to upload the photos, costing at least Dh1 million a year to capture this data. To combat these challenges, a team from New York University in Abu Dhabi has developed a 2.2kg drone that can fly for 1.5 hours for up to 40 km, collecting different types of data including images, salinity and atmospheric data in the mountainous Wadi Wurayah National Park.[38]

In the camera trap, the transmission system uses low-power XBee communications run on solar power, which turns on at regular 2 to 3 minute intervals to check whether the drone is approaching. The system also has a back-up transmission system via Wi-Fi in case of failure. The drone hosts the same XBee and Wi-Fi systems and a microprocessor that is permanently turned on and powered by a litho-battery, which can be recharged from solar power once the drone returns to base. The drones are currently used to assess and evaluate the animal population, rather than climate change per se. However, new applications could include monitoring water quality and salinity in coastal regions and desalination of the coast.

Illegal poaching of large wildlife is a major concern across sub-Saharan Africa. For example, 40,000 elephants were killed illegally in 2014, primarily for their tusks, while demand for the horns of the black rhinoceros has lead to a 96% decline in the species' population from 1970 to 1992, with fewer than 20,000 animals remaining. Every eight hours, a rhinoceros is killed in southern Africa.[39] To combat poaching operations, a wide number of projects are utilizing emerging IoT technologies such as connected drones for surveillance as well as long-range wide area technologies to track wildlife and monitor activity at the boundaries of game parks.[40]

In Timor-Leste, the National Directorate of Fisheries and Aquaculture (NDFA) is working in partnership with the FAO-Spain Regional Fisheries Livelihoods Programme for South and Southeast Asia (RFLP) to introduce a programme using radio location beacons to protect local waters from illegal fishing and to provide emergency response to fishermen in distress. The partnership introduced low-cost personal location beacons (PLBs) as part of a community-based system for identifying illegal, unreported and unregulated fishing. When local fishermen identified illegal fishing boats in the Timor-Leste waters, the location beacon is activated and data is are sent to an Internet-enabled mapping platform used by authorities to track and apprehend illegal fishing boats, or initiate rescue services.[41]

Acoustic sensors have also been developed to monitor wild populations of seabirds. For example, Nexleaf has worked with the US Fish & Wildlife Service and the Coastal Conservation & Action Lab to deploy four sensors on Tern Island from December 2011 to May 2012.[42] The deployment consisted of four wildlife acoustic monitors and two Wi-Fi radio repeaters powered by 20W solar panels, and one gateway computer. The project demonstrated the performance capabilities of satellite-based WSNs for long-term monitoring of seabird colonies.

The United States Forest Service (USFS) has developed a project to study the state of urban and rural forest ecosystems in real-time to keep them healthy and more sustainable.[43] Climate change will also be better understood, and lessons can be learned in order to take advantage of the effects of climate change. USFS has monitored wildlife across the US for decades, manually collecting information from air and soil temperature to

38 http://gulfnews.com/news/uae/government/uae-drones-for-good-award-wadi-drone-makes-conservationists-job-easier-1.1452917

39 http://airshepherd.org/

40 http://airshepherd.org/ and http://gblogs.cisco.com/uki/week-4-how-can-technology-help-the-anti-poaching-activities/

41 Food and Agriculture Organization of the United Nations, "Success Stories on Information and Communication Technologies for Agriculture and Rural Development", available at: http://www.fao.org/3/a-i4622e.pdf

42 http://nexleaf.org/project/tern-island

43 http://smartforests.org/

solar radiation. The IoT is helping to automate some of the data collection activities.

Now, the USFS has developed a sensor-based system to obtain real-time measurements and combine these with traditional field studies and long-term records of patterns and processes to analyze environmental changes. Some sensors reach around trees to measure their growth, others use motion-triggered webcams and sensors to capture pictures of wildlife 24/7 and track the presence (or absence) of endangered species. Sensors detect and deliver high-resolution data wirelessly or through a cellular network to a central web portal. Similarly, Rainforest Connection is using microphone sensors in smartphones to monitor for sounds associated with illegal logging (from chainsaws, trucks and motorcycles).[44]

There are also other interesting developments in relation to commercial crops, often a vital source of income in rural communities. Over the last two decades, the red palm weevil has become a growing threat to palm trees in many parts of the world.[45] Early detection is difficult, since many palm trees may not show visual evidence of infection until it is too late for trees to recover. A prototype bioacoustic sensor has been developed to detect sounds of larvae activity, with wireless reporting to a control station to check the status and evolution of palm tree orchards.

Energy

Another interesting IoT application in the energy sector in developing countries has been the rapid adoption of off-grid solar panel systems that provide steady electrical power to low-income families. As Figure 8 (page 26) highlights, electricity is used by only 58% of the urban population and by only 12% of the rural population in sub-Saharan Africa. Challenges of grid availability, cost of service and frequent service interruptions plague on-grid electricity users across much of the developing world. M-Kopa in Kenya exemplifies this new technology, which is comprised of photovoltaic cells and a battery system and communications model.[46] Individuals purchase the system at a discounted rate with the capital costs amortized over an initial purchase period. After installation in their dwelling, the customers are then able to utilize the electricity generated by the solar cells to power home appliances. They must make regular payments (usually via mobile money systems, e.g. M-Pesa or Airtel Money) in order to continue using the device. M-Kopa is able to remotely monitor the amount of electricity captured/stored and whether the device is working appropriately through the device's connectivity module.

Across the developing world, wood and charcoal burning cook stoves are used extensively to prepare meals and provide a source of heat inside homes. The resulting indoor air pollution contributes to approximately 4 million deaths a year, out of the 3 billion people worldwide who utilize biomass to prepare their meals. As a result, a number of initiatives are in place to help lower income households use less polluting methods for meal preparation and heating in the way of improved cookstove projects. For example, the US Government has supported a five-year "Global Alliance for Clean Cookstoves" which aims to achieve a goal of enabling 100 million homes to adopt clean and efficient cooking solutions by 2020.[47] IoT sensors are playing a role in this initiative by helping measure the black carbon emitted by cookstoves in real-time, as well as monitoring and evaluating projects to disseminate improved cookstoves.

In one particular project in Sudan, the use of improved cookstoves via sensor-enabled recording instruments was compared to traditional survey data (captured by an enumerator) to determine whether the latter method accurately reflected usage captured by sensors. In this case, the study found that survey participants were over-reporting daily cooking hours by 1.2 hours on average, and daily cooking events by 1.3 events. The results suggest that survey-based methods of evaluation may be misstating the actual impact and usage of the newer technologies.[48]

44 Interview with Dave Grenell, Rainforest Connection, on May 19, 2015. https://rfcx.org/

45 www.mdpi.com/1424-8220/13/2/1706/pdf

46 www.gsma.com/mobilefordevelopment/wp-content/uploads/2013/01/Sustainable-Energy-and-Water-Access-through-M2M-Connectivity.pdf

47 http://www.state.gov/r/pa/prs/ps/2015/09/247240.htm

48 "Comparing Cookstove Usage Measured with Sensors Versus Cell Phone-Based Surveys in Darfu, Sudan," by Daniel Lawrence Wilson et al. Chapter 20 of "Technologies for Development: What is Essential."

IoT technologies can be used to produce more accurate data, especially when used in conjunction with subjective perceptions recorded via survey response.

Other Sectors

Examples of IoT deployment impacting other facets of global development abound, and the opportunities to improve service delivery, and other aspects of development work, are limited only by human creativity and the resources available. Table 3 below highlights some of the various IoT interventions as they map to the Millennium Development Goals (MDGs) and the new Sustainable Development Goals (SDGs) as adopted by the United Nations.

Table 3 – Examples of IoT interventions mapped to the Millennium Development Goals (MDGs) and Sustainable Development Goals (SDGs)

Sector	MDG	SDG	Examples
Health, Water & Sanitation	MDG 4: Child Health MDG 5: Maternal health MDG 6: Combat HIV/ AIDS, malaria and other diseases	SDG 3: Ensure healthy lives and promote well-being for all at all ages. SDG 6: Ensure availability and sustainable management of water and sanitation for all.	Sensor- and SMS-enabled village water pumps (Rwanda, Kenya); GSM-connected refrigeration for vaccine delivery in the 'cold chain' (Global); sensor-enabled 'band aid' to monitor Ebola patients' ECG, heart rate, oxygen saturation, body temperature, respiratory rate and position, all remotely (West Africa); water stream gauge with sonar range sensor to monitor river flow and depth (Honduras); water flow sensors and motion detectors in latrines to monitor efficacy of hygiene training and intervention (Indonesia).
Agriculture & Livelihoods	MDG 1: End Poverty & Hunger	SDG 1: End poverty in all its forms everywhere. SDG 8: Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all. SDG 2: End hunger, achieve food security and improve nutrition, and promote sustainable agriculture.	Connected micro-weather stations improving localized weather data and provision of crop failure insurance (Kenya); low-cost mobile-controlled micro irrigation pumps (India); soil-monitoring sensors used to improve tea plantation production (Sri Lanka, Rwanda); RFID-based food supply testing and tracking system (India) and RFID based livestock programmes for tracking, theft prevention and vaccination records (Botswana, Senegal and Namibia).
Education	MDG 2: Universal Education	SDG 4: Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.	Smart identity cards with biometric features for all public school students to improve service delivery (Nigeria); biometric clocking device to improve teacher attendance in real-time (South Africa).
Environment & Conservation	MDG 7: Environment	SDG 12: Ensure sustainable consumption and production patterns. SDG 13: Take urgent action to combat climate change and its impacts. SDG 14: Conserve and sustainably use the oceans, seas and marine resources for sustainable development. SDG 15: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, halt and reverse land degradation, and halt biodiversity loss.	Radio-based cloud-connected devices to identify and track the presence of illegal fishermen (Timor-Leste); air pollution sensors to monitor urban outdoor air pollution (Benin); acoustic sensors to monitor sea bird populations (global); sensors and connectivity to protect game park perimeters and track animals (Africa); connected unmanned aerial vehicles monitor national parks and connecting images from camera traps (UAE); acoustic sensors in tropical rainforests 'listening' for illegal logging (Indonesia).

Table 3 - Examples of IoT interventions mapped to the Millenium Development Goals (MDGs) and Sustainable Development Goals (SDGs) (continued)

Sector	MDG	SDG	Examples
Resiliency, Infrastructure and Energy		SDG 7: Ensure access to affordable, reliable, sustainable and modern energy for all. SDG 9: Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation. SDG 11: Make cities and human settlements inclusive, safe, resilient and sustainable.	Networked fire/smoke alarms in high-density urban slums/informal settlements (Kenya, South Africa); Connected buoys as part of the tsunami monitoring system (Indian Ocean); off-grid micro solar electricity systems for electricity for lower-income households (east Africa, India); connected black carbon- and use sensors to monitor cook stoves (Sudan); sensor-connected matatus (mini-buses) tracking velocity, acceleration, and braking to curb dangerous operation of public transportation (Kenya).
Governance & Human Rights		SDG 10: Reduce inequality within and among countries. SDG 16: Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels.	Retinal scans used for ATMs providing secure biometric cash assistance to displaced refugees (Jordan).
Cross-Cutting	MDG 3: Gender Equality MDG 8: Partnership	SDG 5: Achieve gender equality and empower all women and girls. SDG 17: Strengthen the means of implementation and revitalize the global partnership for sustainable development.	

Challenges to the deployment, scale and impact of the IoT in developing countries

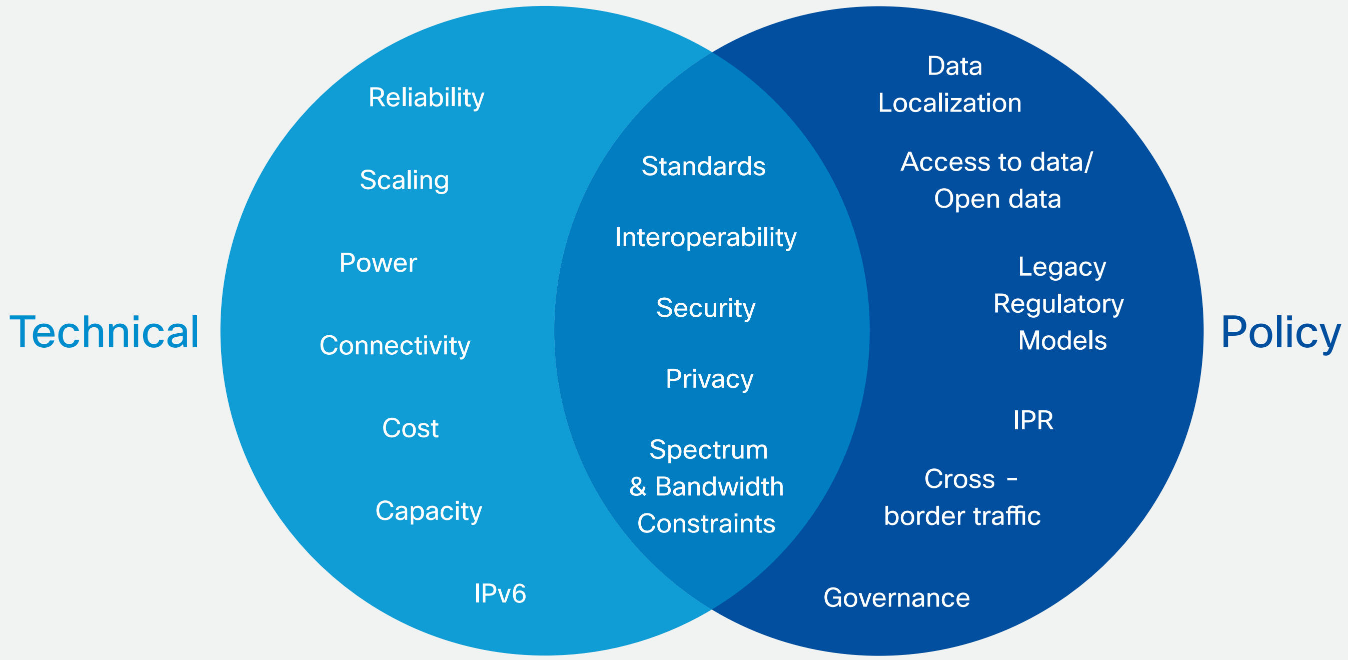
Challenges of the Internet of Things

Despite all the exciting possibilities brought about by the IoT and Big Data, significant challenges persist. The same infrastructure that enables people to create, store and share information may also jeopardize their privacy and security. These same techniques can be used for large-scale and targeted surveillance. Abuse of these techniques could turn the 'Information Society' into the 'Surveillance Society', as identity management systems improve without parallel emphasis on anonymity and ownership of personal data.

Society's most advanced systems and infrastructures are now so complex that some of them are becoming hard to manage effectively. Where they are designed wisely and used effectively, policy and regulatory frameworks can help the development of the IoT. However, outdated or poorly designed frameworks can prove a hindrance and obstacle to the further growth of the IoT. While many parts of daily life become more connected, some remain woefully underconnected. Conversely, other elements of an individual's daily life may be overwhelmed as the explosion of new devices will require new infrastructure and technologies.

Technological and human capabilities are often insufficient in developing countries. Financial support may be lacking. There are often not enough technically literate people with IT skills in local areas who are capable of implementing the use of sensors or other devices into their daily lives. Figure 12 summarizes some of the emerging challenges in relation to the IoT and data.

Figure 12: Summary of Emerging Challenges in relation to the IoT



Source: Pepper, R. & Garrity, J. (2014) The Internet of Everything: How the Network Unleashes the Benefits of Big Data. Global IT Report 2014. WEF. http://www3.weforum.org/docs/GITR/2014/GITR_Chapter1.2_2014.pdf

Technical Challenges

Reliability is a concern with regard to the durability of devices to withstand external conditions. Sensors, too, need to be calibrated to ensure proper measurements. In terms of scalability, the way in which resources are scaled to match growth in the IoT may matter. Data centres, for example, are constantly being redesigned in terms of electrical power, cooling resources, and space design to advance current capabilities. However, the connectivity requirements of billions, as opposed to millions, of connected objects impose very different demands on data centres. As the IoT scales up and expands from billions into tens of billions of connected devices, IP networks have to be able to manage the huge scale of device connectivity.

Power requirements vary greatly, with higher bandwidth devices requiring much more power. Connectivity challenges were discussed earlier, and include limited data network coverage. According to Laura Hosman of Inveneo, the top five hardware challenges in the application of ICTs in development are: electricity/power/energy; cost; environment; connectivity; and maintenance and support.[1] The costs associated with the sensors, connectivity modules and the connectivity service can still prove prohibitive for many interventions (such as for individual small shareholding farmers). Organizations are starting to explore shared models of sensor module ownership such as community ownership, or 'sensors as a service.'[2]

Inadequate human capacity may prove a major issue in some locations. Small-scale organizations may not be trained properly to use the technology. There may also be underlying issues that inhibit training. For instance, if 80% of the target population is illiterate, is SMS text really the best form of communication? There may also be an inadequate number of trained people or technicians to respond, once a system signals a problem. If it is difficult to fix manual pumps on-the-ground, it may be difficult to find the resources to fix more complicated, seemingly mysterious 'black boxes' without back-up strong structures in place to deal with breakdowns.

Further challenges may arise from human behavior as a limiting factor, with reluctance to adopt new technology also a possible concern. People are often resistant and reluctant to modify their behavior to fit with systems, and prefer that systems adapt to meet their needs. Deloitte cites the example of one electrical utility company which installed smart meters in millions of homes in North America, expecting that consumers would consult online dashboards of monthly usage, and modify behavior to save money and energy, benefit the environment. Three years after the meters were deployed, only 6% of households had viewed the dashboard at all, while fewer than 2% had consulted the dashboard more than once.[3] Indeed, according to some projects, human behavior may prove a more significant barrier to adoption than some technical challenges.

In the short-term, the transition to IPv6 has proved challenging for some countries and some organizations to date. However, practically speaking, IPv6 may even prove a limiting factor in some M2M deployments, requiring all partners in a project to have made the transition. For example, partner universities first need to transition to IPv6 before they can implement a WSN project. Government can help play a leadership role in the transition to IPv6, and help aggregate and/or stimulate demand. The migration from IPv4 to IPv6 should help resolve Internet address issues in the long-term, but the short-term challenge of providing adequate address space for billions of objects will persist.

Policy Considerations

Data localization regulations and limits on cross border traffic may impede the ability of managers to send data to cloud-based servers where data may be analyzed. While Open Data policies are increasing adopted, there are examples of governments clamping down on access to data collected and generated by sensors.[4]

The IoT has regulatory implications across a set of areas,

1 http://www.inveneo.org/wp-content/uploads/2014/07/FINALTop-ICT-Hardware-Challenges-White-Paper.pdf

2 http://www.slate.com/articles/technology/future_tense/2015/06/community_drones_helps_indonesia_s_dayaks_protect_their_land.html

3 Deloitte Tech, Media & Telecoms (TMT) Predictions 2015.

4 www.washingtonpost.com/blogs/monkey-cage/wp/2015/04/08/five-charts-that-may-soon-be-illegal-in-tanzania/

including licensing, spectrum management, standards, competition, security and privacy – only some of which are the familiar territory of telecom regulators, compared with other areas where different regulators may typically take the lead. The 'full' IoT or Internet of Everything (IoE) is likely to require more 'joined up' regulation, with telecom/ICT regulators working more closely with their counterparts in data protection and competition, but also with emergency services, health and highway authorities, as legacy regulatory models (e.g. power utility regulations) may prove inadequate to deal with emerging technologies (e.g. 'smart grid' technologies).

Similarly, broader governance issues may impede the adoption of the IoT, such as in the case of the slow adoption of connected thermometers to protect the vaccine cold chain due to challenges in certification approval for new technologies in the World Health Organization's Pre-Qualified Systems (PQS).

Overlapping Issues

The proliferation of, and growth in, new IoT technologies are built mainly on interoperability. In order for a car, airplane, parking meter or pill bottle to send and receive important data, it needs to be able to connect to other systems and networks seamlessly and securely. Interoperability is the ability to transfer useful data and other information across systems, applications, or components in four broad layers – technological; data; human; and institutional.[5] According to one source, there are at least 115 different protocols used by IoT devices to connect to the cloud today.[6] A recent paper by McKinsey notes that "interoperability is required to unlock more than US$4 trillion per year in potential economic impact for IoT use in 2025, out of a total impact of US$11.1 trillion. On average, interoperability is necessary to create 40% of the potential value that can be generated by the IoT in various settings."[7]

Although various approaches exist to help promote interoperability, standards are one collaborative approach to interoperability, and can achieve high levels of interoperability.[8]

Privacy and security are often cited as two of the most significant (and closely related) issues in large-scale IoT deployment. Privacy, security and anonymity are all related, but separate, concepts. Privacy (related to confidentiality) is the ability to define the intended target audience for data. Anonymity is the quality or state of being unknown to most people. A secure system is a system free from weakness or vulnerability. For example, electronic health files and car license plates are private (and confidential), but not anonymous. A breach of security may or may not result in a loss of privacy, depending on the data downloaded and how it is subsequently used. While ICTs do provide greater opportunities for communication and income related activities for lower-income populations, careful consideration is needed of the risks associated (loss of privacy, etc.).

Without adequate security, intruders can break into IoT systems and networks, accessing potentially sensitive personal information about users, and using vulnerable devices to attack local networks and devices, thereby breaching their privacy. This is a particular issue when devices are used in private spaces, such as in individuals' homes. Operators of IoT systems, as well as others with authorized access to the data produced, are likely to be in a position to "collect, analyze, and act on data from within previously private spaces".[9]

Privacy concerns may still arise, even where systems are secure and functioning as intended. For example, does sponsorship of projects by third parties entitle them to access the resulting data? Third parties almost invariably respond that the data are high-level and aggregated, making it anonymous, or that they are using the data for beneficial purposes that outweigh any loss in privacy.

Another issue related to privacy and anonymity is the address space of connected devices. Identifiers used in one network need to be understandable and/or usable (i.e. interoperable) in another network. In the Internet of

5 GSR Interoperability Discussion Paper by Urs Gasser, Berkman Center.

6 NetHope SDG ICT Playbook. Available at: http://solutionscenter.nethope.org/assets/collaterals/NetHope_SDG_ICT_Playbook_Final.pdf

7 Manyika, James, et. al., The Internet of Things: Mapping the Value beyond the Hype. McKinsey Global Institute, June 2015. p. 2.

8 GSR Interoperability Discussion Paper by Urs Gasser, Berkman Center.

9 GSR Discussion Paper on IoT by Prof. Ian Brown, Oxford Internet Institute..

Things, consumers will likely want to use different objects across multiple kinds of heterogeneous networks, which will need the identities of things to be "federated" or capable of being translated accurately and recognized by different networks. The IoT will contain billions of objects that must be uniquely identified, a challenge for which there is currently so far no internationally-agreed solution, although Internet Protocol version 6 (IPv6) may eventually become the default solution.

On a more practical level, lock-in to mobile service providers is a real likelihood for many projects. Firms operating large networks of IoT devices via mobile telephony networks using a fixed SIM in each device may not find it easy to switch network at the end of a contract, or where there is device roaming in different network areas.

It could also be very difficult to renegotiate the terms of the mobile contract, or swap service temporarily to take advantage of better service from a different provider, raising concerns of anti-competitive behaviour.

Spectrum and bandwidth requirements may impede the adoption of IoT devices and services. According to Cisco's 2015 *Visual Networking Index* study, over 10 billion new devices will come online between 2014 and 2019, and total global IP traffic is growing at 23% Compound Annual Growth Rate (CAGR).[10] While the sheer diversity of IoT devices will result in a wide range of network requirements, the aggregate impact will lead to increasing demands for wireless spectrum to support wireless data transmission. A flexible and sufficient spectrum bandwidth regime will be necessary to ensure innovation and adoption are not stifled.

10 Cisco Visual Networking Index 2015, at http://www.cisco.com/c/en/us/solutions/service-provider/visual-networking-index-vni/index.html

Photo credit: Marco Zennaro. Engineer with a GSM-enabled soil moisture sensor node in a tea factory plantation in Rwanda.

Recommendations

A number of enabling policies can be put in place to facilitate the deployment of the Internet of Things, as well as Big Data. As explained previously, policies to support rapid and effective adoption of the IoT need to involve a range of stakeholders to help promote successful deployments. At the national level, policies can be put in place to support and facilitate the fast development of IoT, as well as eliminate the barriers and challenges to be overcome (described in the last section). Some key aspects to be considered include:

1. Create a policy framework and master plan addressing the IoT – as the IoT is likely to become a huge sector on its own right in a number of countries, countries wishing to take advantage of its benefit should develop a master plan and/or additional funding for broadband including consideration of the IoT to accelerate the growth of the IoT and to capitalize on these benefits. In the UK for instance, Prime Minister David Cameron announced [in March 2014] an additional GBP 45 million funding for the development of IoT.[1] Malaysia's Ministry of Science, Technology and Innovation and its applied research agency released a National Internet of Things (IoT) Strategic Roadmap in mid-2015.[2] Independently, some donor partners in the ICT4D community have also established "Principles for Digital Development" that aim to facilitate the adoption of the IoT in development.[3] Governments and policy-makers should work closely with industry to understand the issues involved. This policy should also consider how new IoT systems can interface with pre-existing legacy infrastructure to protect and make full use of existing investments in infrastructure.

2. Give consideration to sourcing any additional spectrum which may be needed for IoT. As discussed in Section 2, connectivity and therefore spectrum is a key part of supporting the expansion of the IoT. Efficient and effective spectrum management is therefore key for ensuring efficient connectivity. In December 2015, Australian authorities freed up additional spectrum bands dedicated to the use of IoT and M2M.

3. Promote and support a broad, vibrant ecosystem for IoT, including support for tech start-ups and incubators. This includes promoting policies to facilitate innovation and development and eliminate policies that restrict or prevent innovation (such as restrictions to the free movement of data or the ability to trade in digital services).

4. Promote Data Centres – Depending on the centralized or decentralized nature of the IoT deployments in a country, it may be helpful to launch more local data centres, supported by reliable and quality electricity, tailored tax incentives, and low or more flexible labour costs.

5. Promote standards that facilitate interoperability across the IoT ecosystem, foster investment, competition and scale to enable cost-effective solutions.

6. Trust and confidence in the IoT are fundamental and must be designed into the IoT from the outset. Two key components to ensure trust and confidence are privacy and security: a) Strategies to protect privacy must take a range of risks into account from a variety of different sources as well as adapt to local regulations; and b) Accelerate research into IoT-related security threats to minimize the downsides of the IoT across M2M and M2P communications. The exponential growth of increased attack vectors (in terms of type of data generated and the variety of things and devices connected to the Internet) may give attackers easy ways to access networked data.

This report has made the case for the use of IoT to improve people's lives around the world. It has outlined a number of practical and technical considerations in the deployment of IoT systems in the hope of improving outcomes in development projects and accelerating the adoption of IoT in developing countries to improve people's lives.

1 "'Internet of things' to get £45m funding boost", 9 March 2014, available at: http://www.bbc.com/news/business-26504696

2 https://www.telegeography.com/products/commsupdate/articles/2015/07/14/malaysia-publishes-national-roadmap-for-iot/?utm_source=CommsUpdate&utm_campaign=9add5560b9-CommsUpdate+14+July+2015&utm_medium=email&utm_term=0_0688983330-9add5560b9-11619241

3 http://digitalprinciples.org/

Annexes

Annex 1: Projects By Sector

This Annex presents a glossary of additional information about projects mentioned in this report.

Health

NexLeaf Analytics — Cold Chain Monitoring

Nexleaf Analytics is a non-profit technology company that builds wirelessly connected devices and sensor technologies for critical public health and environmental interventions. Currently in the pilot phase, NexLeaf's cold chain monitor uses mobile phones to collect and wirelessly transmit temperature data from refrigerated units that store and transport vaccines. From warehouse to clinic, sensors wirelessly upload temperature data, correlate that data with geolocation of the phone, and generate SMS and email alerts about vaccines and other drugs reaching critical temperatures. By providing real-time information on equipment health and vaccine safety, supply chains become more secure, while tracking of historical vaccine distribution patterns is enabled, which can improve forecasting and capacity planning in the future.

http://nexleaf.org/technology/cold-chain-monitor

Smart Connect – Cold Chain Monitoring

Smart Connect is a "communication appliance" developed by PATH and Inveneo that uses SMS to improve the reliability and performance of one of the most important systems in all of global health: the medical "cold chain". With over 200,000 vaccine refrigerators in use in the developing world alone, most of them in harsh and remote environments, keeping the cold chain up and running is a major challenge that Smart Connect seeks to overcome. The device was developed to confront communication barriers and address the cold chain challenge by bringing a "digital dial tone" to remote health posts in the developing world. Representing a significant departure from the traditional method of tracking and recording refrigerator temperatures, Smart Connect now records the temperature and sends out alert messages whenever there is a problem. Messages are then sent to a website and automatically relayed to service technicians who can respond immediately. Additionally, managers have access to daily summaries of the refrigerators' temperatures, which are posted online to the Smart Connect website.

http://homes.cs.washington.edu/~eorourke/papers/smart_connect_nsdr.pdf

STAMP2

The United States Agency for International Development (USAID) has supported and employed IoT solutions via connected wearable technologies, most recently through its backing of the Sensor Technology and Analytics to Monitor, Predict, and Protect Ebola Patients program (STAMP2 for short), created by the Scripps Translational Science Institute (STSI). This intervention has been tested on Ebola patients in the United States and is being scaled up to meet the needs of other government agencies for the Ebola treatment strategy in Liberia. STAMP2 collects patient data, including ECG, heart rate, oxygen saturation, body temperature, respiratory rate and position. This data is then sent to a centralized platform so it can be monitored and analyzed over a long period of time to alert physicians to abnormal changes in a patient's behavior or health. The STAMP2 sensor will be deployed in Ebola-stricken areas using a connected health patch or "Smart Band-Aid". The fully equipped sensor-enabled band-aid is estimated to cost approximately US$100 with a maximum battery life of 10 days – making it ideal for use in field-based Ebola treatment centers. Deployment of the STAMP2 sensor would improve the broader Ebola response initiative by reducing emergency response times in critical areas and enabling emergency responders to detect Ebola patients earlier and to monitor them more efficiently.

http://mobihealthnews.com/40564/scripps-wins-usaid-grant-to-monitor-ebola-patients-with-medical-wearables/

Water & Sanitation

The Hidrosonico Project

Water flow sensors are being used to aid in the collection of hydrological data in developing countries where local data on river flow and levels may not be regularly collected. These sensors can also help with early warning for flooding. The Hidrosónico is a water stream gauge that uses sonar range sensors to measure the distance to water surface level. The module sends the readings on regular basis to recipients (via SMS or email) or to a cloud application. The unit is also equipped with a rain gauge to monitor precipitation, and is currently deployed in Honduras.

http://dai.com/our-work/solutions/dai-maker-lab; https://github.com/DAI-Maker-Lab/hidrosonico

RW Siaga Plus+ Program

Between September 2009 and September 2011, Mercy Corps in Indonesia conducted and evaluated various approaches to their water and sanitation programme RW Siaga Plus+, in the Indonesian kelurahan (sub-district) of Margahayu, Bekasi, as well as in sixteen poor urban neighborhoods in three other kelurahan located throughout West Jakarta. A major goal of this programme was the creation of healthy physical environments in urban poor settlements through increased access to clean water supplies and improved sanitation. Using two different evaluation methods, the organization and its partners measured the programme's effectiveness on achieving behavioral change and overall programme targets, enabled by data collected from water flow sensors deployed in the field. In one programme delivering water, hygiene and sanitation interventions, flow sensors, in combination with motion detectors, amassed data that was used to measure the impact of behavior change training, with the intent of increasing hygienic actions (washing after latrine use). The study found community participants were washing hands after latrine usage; however, the survey responses (those who indicated they wash their hands after using the latrine) were significantly higher than the data captured by the motion sensors, suggesting over-reporting in the verbal and self-reported surveys.

http://www.mercycorps.org/sites/default/files/Instrumented%20Monitoring%20Indonesia.pdf

SmartPump (Mobile Enabled Transmitter) - Maintenance Service Provider Model

The Smith School of Enterprise and the Environment at Oxford University, in conjunction with the UK Department of International Development, conducted a study in the Kyuso District of Kitui County, Kenya, from August 2012 until December 2013, in which water pumps were equipped with GSM transmitters that sent data via SMS over existing mobile phone networks. Following a series of proof-of-concept tests in Lusaka (July 2011), transmitters were installed in 21 handpumps, that offered: (1) measurement of handpump usage and associated volumetric water use; (2) remote surveillance of maintenance service delivery and downtime; and (3) objective data to improve infrastructure planning and investment, and promote sector accountability. Data transmitted from pumps are captured in a relational database and presented using a bespoke graphic user interface. The Ministry of Water and Irrigation, the Water Services Regulatory Board and the District Water Office were consulted for their inputs. The results of the study are compelling: 98% of handpumps now work in Kyuso (compared to a rough estimate of 70% in Africa), five times more revenue is being collected, handpump downtime reduced 10-fold from 27 days to less than 3 days, and now 80% of users are willing to prepay after the trial (compared to less than 20% before the trial).

http://www.smithschool.ox.ac.uk/library/reports/SSEE_Rights to Results_FINAL_March2014.pdf

SWEETSense - CellPump

SweetSense Inc. provides low-cost remote monitoring solutions for water, energy, and environmental projects to reduce client operating costs, improve technical performance, and increase overall effectiveness. The social enterprise corporation, in collaboration with Portland State University's SweetLab, has developed CellPump, a smart sensor that can be installed within the pump head of Afridev and India Mark 2 water pumps. Water flow data are transmitted by sensors over GSM cellular networks (98% of the country has cell coverage) and monitored by Living Water International via an online dashboard. Currently over 200 sensors have been provided for Living Water International, deployed in various remote villages in Rwanda. The project is supported in part by the GSM Association and the UK Department for International Development, and has been implemented in partnership with MTN, the Rwanda Ministry of Natural Resources, and other local government authorities.

http://www.sweetsensors.com/applications/cellpump/

WellDone - MoMo

WellDone builds technological tools that empower resource-constrained communities with the data they need to invest in and maintain lasting critical infrastructure. The organization works at the local level to ensure that these communities become independent of development assistance, and focuses on the distribution of technology that facilitates more reliable and robust infrastructure development. Notably, MoMo (mobile monitor) is a mobile device produced by WellDone that collects data to track the progress of infrastructure projects, report on their progress, and notify appropriate personnel when maintenance is required. MoMo has been used in handpumps, measuring their functionality, their frequency of use, and their hourly water flow. The data generated by remote MoMos are then aggregated using WellDone's Smarter Villages software, which alerts local repair teams by SMS whenever a well in their area breaks down. The software also displays trends in water use, which can be used at the local, and potentially national, level to better allocate resources and plan projects according to levels of need.

https://welldone.org

Agriculture & Livelihoods

Kilimo Salama - Connected Weather Station

Beginning in 2009 with a pilot project offering index insurance to 200 farmers in Kenya, the Syngenta Foundation's Kilimo Salama ("Safe Farming") weather index insurance programme has helped over 51,000 farmers in Kenya and 14,000 farmers in Rwanda to date. The programme's solar-powered weather stations collect weather data every 15 minutes, which are then aggregated and compared to historical weather data at the end of each growing season. Any payout owed is calculated and sent to farmers via mobile phone. Syngenta, on behalf of Kilimo Salama, partnered with Safaricom in 2010, providing a less expensive and dense communications network for product sales and customer communication. Using Safaricom's M-PESA mobile banking system, the programme keeps index insurance premiums affordable for smallholder farmers, who receive their index insurance policy numbers and premium receipts via SMS. Payouts are sent electronically through M-PESA as well, which has reduced the associated risks of adverse weather and provided farmers with a financial safety net. Subsequently, the regions that have participated in the Kilimo Salama programme have enjoyed increased agricultural investment and improved wellbeing, while partnering microfinance institutions have seen their loan portfolios increase in value, sometimes by as much as double within the first six months.

http://www.ifc.org/wps/wcm/connect/e0ed35804c33fc309479def12db12449/KS+story.pdf?MOD=AJPERES

Nano Ganesh – Micro Irrigation Solution

In India, the Nano Ganesh solution is a low-cost product set to provide small-shareholder farmers with a tool that can remotely control their micro irrigation pumps. In India, about 25 million water pumps are in use for farm irrigation. Many of these pumps have to be manually operated, based on rainwater conditions, electricity availability and crop needs. For the average small-scale farmer, the variability of these factors on a day-to-day basis adds extra burdens in terms of time, labor and fuel costs. In many cases, farmers need to travel long distances and/or through difficult conditions to access their pumps from their households. The Nano Ganesh unit works by attaching to the irrigation pump, and serving as an actuator, which can turn on and off via basic commands from the farmer's simple feature phone (2G). The farmer is also able to check the availability of electricity at the pump, as well as the availability of water near the pump (with an additional water sensor). As of August 2014, twenty thousand farmers in India are benefiting from Nano Ganesh.

http://www.fao.org/3/a-i4622e.pdf

Sensors for Tea Plantations

The quality of tea, and its resulting sales price, are determined in part by water composition of its soil and surrounding environment. As a major export of Sri Lanka and Rwanda, it is essential that moisture levels be monitored and recorded; however, traditional manual methods have proven inefficient and time-consuming. Plantations in both countries utilize WSNs to monitor moisture, pH levels, carbon, nitrogen, potassium, calcium and magnesium levels of the soil in which their tea grows. Sensors and connectivity modules are powered by solar panels, and the data that they capture are transmitted wirelessly. At a relatively low cost, sensors deployed in the field provide actionable feedback every fifteen seconds, saving time, money, and crops.

http://wireless.ictp.it/rwanda_2015/

http://www.ictp.it/about-ictp/media-centre/news/2015/6/teatime-with-iot.aspx

http://wireless.ictp.it/school_2015/presentations/CaseStudies/IoTforTeaPlantation-SriLanka-Minuri.pdf

Timor-Leste's Community-Based IUU Reporting System

In Timor-Leste, the National Directorate of Fisheries and Aquaculture (NDFA), working in partnership with the FAO-Spain Regional Fisheries Livelihoods Programme for South and Southeast Asia (RFLP), introduced a plan using radio location beacons to protect local waters from illegal fishing and to provide emergency response to fishermen in distress. The partnership introduced low-cost personal location beacons (PLBs) as part of a community-based system for identifying illegal, unreported and unregulated fishing. Now, when local fishermen identify illegal fishing boats in the Timor-Leste waters, the location beacon is activated and data are sent to an Internet-enabled mapping platform, which authorities utilize to track and apprehend illegal fishing boats or initiate rescue services.

http://www.fao.org/3/a-i4622e.pdf

Resiliency, Climate Change, & Pollution Mitigation

Fresh Air in Benin

Urban air pollution is a major problem in many developing country cities. The World Health Organization (WHO) attributes one in eight deaths worldwide to polluted air, as dirty air causes lung damage, heart disease, strokes and cancer. The WHO also estimates that indoor air pollution in homes in Africa contributed to nearly 600,000 deaths in 2012. To measure the extent of the problem, air quality sensors are being deployed in a range of cities to track levels and changes in pollutants. One such project, Fresh Air in Benin, is focused on developing a network of air quality sensors to capture and send data every 20 minutes via GSM connectivity.

https://docs.google.com/folderview?id=0B_lA8alw74UiVGJuU0hGV01scVE&usp=docslist_api&tid=0B81LFtxt5uZKeEphNG9PRTFPR2c

Smart Fire Sensors for Slums & Informal Settlements

A regularly occurring tragedy in high-density urban slums, fires are particularly deadly given the rapid and haphazard nature of these neighborhoods' development, including narrow doorways that are often blocked, high population density, and the lack of adequate first response. The Red Cross has proposed that local entrepreneurs help solve the problem by installing connected fire alarm systems across slums and other informal settlements to quickly notify residents when a fire first starts. The organization has also explored the option of developing low-cost, solar-powered sensors networked together to quickly detect when a fire has broken out and notify the dwelling's resident(s), as well as surrounding neighbors. Upon detection of smoke, the network sounds an alarm and communicates the threat to other homes nearby through SMS or other modalities. Additionally, the networked sensors are GPS-enabled and have the ability to identify a fire's point of origin and transmit that information to authorities so that they may more accurately target fire extinguishment efforts. Currently, the intervention is being tested in Nairobi and Cape Town, with participation by two thousand households.

https://drive.google.com/file/d/0B1vf6TLGIC0yZk9UU2t2UGFmNlE/view?usp=sharing

South Indian Ocean Tsunami Warning System

Following the 2004 Indian Ocean tsunami that devastated coastal areas in India, Sri Lanka, Thailand and Indonesia, the international community united to establish the Indian Ocean Tsunami Warning System whereby kinetic sensors (measuring waves and water flow) placed on the ocean floor communicate data on potential tsunamis to disk buoys floating on the ocean surface via acoustic telemetry. Once collected, buoys then upload the information to government authorities via satellite connectivity.

http://www.kophuket.com/phuket/homemenu/tsunami.html

http://iotic.ioc-unesco.org/indian-ocean-tsunami-warning-system/tsunami-early-warning-centres/56/national-tsunami-warning-centres

Echo Mobile - Fleet Management for Public Safety

In Kenya, a large share of road traffic accidents occur in the semi-formal public transport sector using minibuses (known as matatus). With a third of the population relying on informal transit, unsafe driving practices are a substantial cause of preventable death. The challenge is that mini-bus owners lease buses daily to their drivers but cannot observe the drivers' behavior. As most drivers are paid for each route they complete, they may adopt reckless habits: speeding, weaving between lanes, and driving on sidewalks. Misaligned incentives lead to an unsafe transport system particularly for passengers. Echo Mobile has developed a sensor-based system for vehicle owners to track where and how their vehicles are being driven. The technology includes an in-vehicle sensor monitor that reports on vehicle velocity, acceleration, heavy-braking, and transmits data via GSM. A web application collects and analyzes each device's data streams, launching notifications to stakeholders (driver, owner, fleet manager, municipality). An Android application, coupled with SMS alerts, gives owners access to detailed real-time information about each vehicle in their fleet. Through the application, owners (and other stakeholders) can drill down into information on locations, routes, and recent productivity and safety events and take action against unsafe drivers.

https://www.echomobile.org

http://pedl.cepr.org/sites/default/files/Research%20Note_Mitigating%20Market%20Frictions%20by%20Monitoring%20SME%20Employees_3022.pdf

Natural Resource Management

Acoustic Sensors for Seabird Monitoring & Identification

Funded with a grant from the National Science Foundation, Nexleaf Analytics is developing and testing a low-cost tool to remotely monitor seabirds, their first targeted colonies located in Northern California and other locations in the Pacific island region. From December 2011 through May 2012, the organization worked with the U.S. Fish & Wildlife Service and the Coastal Conservation & Action Lab at the University of California at Santa Cruz to deploy four sensors on Tern Island, located in the French Frigate Shoals in the North-West Hawaiian islands. The deployment consisted of four wildlife acoustic monitors and two Wifi radio repeaters powered by 20W solar panels, and one gateway computer. An estimated 400 MB of data were generated daily. The project demonstrated the performance capabilities of satellite-based WSNs for long-term monitoring of seabird colonies, a method which may prove useful for other projects dedicated to conservation efforts or natural resource management.

http://nexleaf.org/project/tern-island

Anti-Poaching Interventions

Illegal poaching of large wildlife is a major concern across Sub-Saharan Africa. In 2014 alone, 40,000 elephants were illegally killed, primarily for their tusks, which are highly sought after in the ivory trade. From 26 million elephants in 1800 to fewer than one million today, the African elephant is at risk of extinction by illegal poaching, but it is not alone. Demand for the horns of the black rhinoceros has lead to 96% decline in the species' population from 1970 to 1992, with fewer than 20,000 animals remaining. To combat these and other poaching operations, a wide number of projects have commissioned emerging IoT technologies, such as connected drones for surveillance, as well as long-range wide area technologies, to track wildlife and to monitor activity at the boundaries of game parks.

http://airshepherd.org/

http://gblogs.cisco.com/uki/week-4-how-can-technology-help-the-anti-poaching-activities/

Wadi Drone

The Wadi Drone is a fixed wing airplane with a 2.5 metre wingspan carrying a small communications payload that retrieves information from ground-based scientific measurement devices. Comprising four NYU Abu Dhabi students, the Wadi Drone development team collaborated with the Emirates Wildlife Society (WWF) and the country's first national park, Wadi Wurayah National Park located in Fujairah, to craft and deploy the drone, which was a 2015 finalist in the UAE Drones for Good Award competition. Within the parameters of the national park, the drone flies over mountains and through valleys to wirelessly download photographs taken by ground-based camera traps that automatically capture images of wildlife as they pass in front of the camera's motion sensor. Collecting data via permanent communications infrastructure could interfere with the natural environment or endanger workers, and the Wadi Drone project assists the conservation efforts of the Emirates Wildlife Society by both increasing the rate at which photographic data of wildlife can be analyzed by experts, and by reducing the human risks associated with the current method of hiking to retrieve photos from remote camera traps. Wadi Drones further eliminate the need to employ a costly helicopter to reach camera traps during the summer months, when high temperatures make hiking conditions dangerous.

http://wadi.io

Rainforest Connection

Rainforest Connection transforms recycled smartphones into autonomous, solar-powered listening devices that can pinpoint signs of destructive activity at great distance. It is a scalable, real-time logging detection system, pinpointing deforestation activity as it occurs. With an initial field project only located in Sumatra, Rainforest Connection (RFCx) is now expanding to three more endangered areas in the rainforests of Indonesia the Amazon, and Africa. By partnering with local communities, indigenous groups, and organizations that are committed to responding to real-time interventions, the organization hopes to demonstrate that their system of next-generation devices can operate on a global scale, in any forest, anywhere.

https://rfcx.org

Energy

M-KOPA Solar

M-Kopa, a pay-as-you-go Energy Service Company (ESCO) for off-grid customers in Kenya, leverages machine-to-machine (M2M) technology to fulfill its mission of providing high-quality energy at an affordable rate to everyone. Their solar home system from D.Light Design is comprised of photovoltaic cells, a battery system and a communications model, which individuals purchase altogether at a discount with capital costs amortized over a designated purchase period. After the system is installed, customers are able to utilize the electricity generated by the solar cells to power home appliances. Following an initial deposit, they must make regular payments (usually via mobile money systems, e.g. M-Pesa or Airtel Money) to continue using the device. M-Kopa remotely monitors the amount of electricity captured, the allocation that is stored, and, through the device's connectivity module, if the device is working appropriately.

http://www.m-kopa.com

Monitoring & Evaluation of Cookstoves

Across the developing world, wood and charcoal-burning cookstoves are used extensively to prepare meals and to provide a source of heat inside homes. The resulting indoor air pollution contributes to approximately 4 million deaths a year, out of the 3 billion people worldwide who utilize biomass to prepare their meals. In response, a number of initiatives are in place to help lower-income households transition to less injurious methods of meal preparation and heating by way of improved cookstove projects. The U.S. Government has supported a five-year initiative of the "Global Alliance for Clean Cookstoves" which aims to achieve a goal of enabling 100 million homes to adopt clean and efficient cooking solutions by 2020. IoT sensors play a major role in this initiative by helping to measure in real time the black carbon emitted by cookstoves, and also in the monitoring and evaluation of projects that disseminate upgraded cookstoves. In one particular project in the Sudan, the use of improved cookstoves via sensor-enabled recording instruments was compared to traditional survey data (captured by an enumerator) to determine whether the latter method was accurately reflecting usage captured by sensors. In this case, the study found that survey participants were over-reporting daily cooking hours by 1.2 hours on average, and daily cooking events by 1.3 events. The results suggest that survey-based methods for monitoring and evaluation may be misleading in their presentation of actual impact and usage. According to the results of this study, data collected by sensors therefore represents the more reliable method.

http://www.state.gov/r/pa/prs/ps/2015/09/247240.htm

Wilson, Daniel L., et. al. "Comparing Cookstove Usage Measured with Sensors Versus Cell Phone-Based Surveys in Darfu, Sudan." Technologies for Development: What is Essential.

Annex 2: Different Characteristics of Wireless IoT Connectivity Technologies

Wireless Technology Type	Technology Name	Max Range	Max Bandwidth/ Data Throughput	Operating Life (Battery)	Module Cost	Spectrum/ Operating Frequency	Spectrum License
WPAN	ANT+	30m	1 Mbps	Days	$1 - $15	2.4 GHz	unlicensed
	Bluetooth 4.0 LE	50m	24 Mbps	Hours	$1 - $15	2.4 GHz	unlicensed
	RFID	Passive: 10m Active: 100m	100 Kbps	Passive Tags: n/a Active Tags: years	Passive: <$1-$5 Active: $5-$25	120-150 kHz; 12.56 MHz, 433 MHz, ISM bands (868 MHz, 900 MHz), 2.5-5.8 GHz	unlicensed
	NFC	10cm	424 Kbps	n/a	<$1	13.56 MHz	unlicensed
	802.15.4g	200m	200 Kbps	Up to 4 years	$1-$15	2.4 GHz	unlicensed
	ZigBee	10-100 meters	250 Kbps	up to two years	$1 - $15	2.4GHz/ 900Mhz (915 MHz, 868 MHz)	unlicensed
WLAN	Wi-Fi	300m	250 Mbps (802.11n); 54 Mbps (802.11a/g); 11 Mbps (802.11b); 1Gbps (802.11ac)	4-8 hours(com) 50 hours (idle)	$10+	2.4GHz/5GHz	unlicensed
	Wi-Fi (802.11ah)	up to 1000m	100 kbps (802.11ah)			Sub-1 GHz ISM bands – Europe (863-868.6 MHz); Japan (950.8 MHz – 957.6z MHz); Korea (917-923.5 MHz); USA (902-928 MHz)	unlicensed
WWAN	LoRa	2-10 km	200Kbps	10-20 years (idle), 120 hours communicating	$1 - $15	ISM bands (868 MHz in Europe; 900 MHz in US)	unlicensed
	Weightless	2-10 km	200Kbps	10 years	$1 - $15	Weightless-N: ISM bands (868 MHz in Europe; 900 MHz in US); Weightless-W: TVWS	unlicensed
	Dash 7	2 km	200 Kbps	Up to 10 years	$1 - $15	433 Mhz	unlicensed
	WiMax	40 km (30 miles)	34 Mbps – 1 Gbps	Hours	$1- $15	No uniform global licensed spectrum but WiMAX forum published 3 licensed spectrum profiles: 2.3 GHz; 2.5 GHz; 3.5 GHz	licensed
	2G (GSM, GPRS, EDGE)	35 km	9.6 Kbps – 384 Kbps	4-8 hours (com) 36 days (idle)	$1 - $15	Global GSM bands	licensed
	3G (UTMS, HSPA)	up to 100km	384 Kbps – 10 Mbps	2-4 hours (com) 20 days (idle)	$35-$50	Various - licensed	licensed
	Cellular 4G/ LTE	up to 100km	3 Mbps – 100 Mbps	2-3 Hours (com) 12 days (idle)	$80-$120	Various - licensed	licensed

Note: Non-exhaustive. Source: Cisco Systems.

Annex 3: Sample Sensor Prices (Retail)

Sensor Name	Price (rounded up)
Integrated WiFi High Temperature Sensor	$204
Integrated WiFi Humidity Sensor	$180
Dual-Range Force Sensor	$110
Ultrasonic Range Finder; CO2 Sensor	$100
Gas Pressure Sensor	$83
Vernier Motion Detector	$75
Oxygen Sensor	$60
RFID Starter Kit; Voice Recognition Shield; Color Detector Sensor; JPEG Color Camera TTL Interface; Soil Temperature and Moisture Sensor	$50
Wind Speed Sensor	$45
Humidity & Temperature Sensor	$42
Multichannel Gas Sensor; Liquid Level Sensor; Soil Moisture and Temperature; Liquid Level Sensor; GPS Breakout Sensor; Wearable GPS Module	$40
G5 Water Flow Sensor; RFID Reader; RFID Sensor Module; Ultrasonic Range Finder Lite; Temperature and Humidity Sensor Board;	$30
Distance and Gesture Sensor; Liquid Flow Meter Nominal Thread; Ultrasonic Rangefinder; Infrared Distance Sensor	$25
AttoPilot Voltage and Current; Pressure Sensor (up to 100 lbs); Pressure Sensor; High Accuracy Barometer; Temperature and Humidity Sensor	$20
Humidity Sensor	$17
G1 Water Flow Sensor; Camera Module; Dust Sensor; Weight Sensor 400kg	$16
Ultrasonic Range Measurement Module; Barometric Sensor; Infrared Proximity Sensor; RGB and Gesture Sensor; Temperature and Humidity Sensor; Triple-axis accelerometer; IR Distance Sensor	$15
Low Accuracy Barometer; Grove Gesture Sensor	$14
Coulomb Counter; UV Sensor	$13
AC Current Sensor high amperage	$12
Sound Detector	$11
Capacitive Touch Sensor; Load Sensor (up to 50kg); Air Quality Sensor; FM Receiver; Temperature and Humidity Probe; Barometric and Temperature Sensor; Altitude Sensor; Digital UV Index/IR/Visible Light Sensor; Proximity Light Sensor; Liquid Flow Meter; PIR Motion Sensor	$10
Current Sensor; PIR Motion Sensor; Collision Sensor; Temperature and Humidity HP Sensor	$9
RGP Light Sensor; Alcohol Sensor; RGB Color Sensor and IR Filter	$8
Infrared shooting sensor; AC Current Sensor; HDR Digital Light Sensor; Microphone Amplifier	$7
Luminosity Sensor; Loudness Sensor	$6
Infrared reflective sensor; RFID Capsule; Ambient Light Sensor; Moisture Sensor; Sound Sensor	$5
Vibration Sensor; Water Sensor	$3

Source: Website review of sensors prices August 6 – 11, 2015 from Sparkfun, Seeed Technology Inc., Adafruit, and Monnit.

List of Acronyms and Abbreviations

API	Application Programming Interface
FDA	Federal Drugs Agency (of the United States)
GSMA	Global System for Mobile Association
IoE	Internet of Everything
IoT	Internet of Things
ITU	International Telecommunication Union
M2M	Machine-to-Machine
M2P	Machine-to-Person
MDGs	Millennium Development Goals
NFC	Near Field Communications
P2P	Person-to-Person
PLB	Personal Localization Beacon
SDGs	Sustainable Development Goals
UN	United Nations
US	United States
US$	United States Dollar
WHO	World Health Organization
WLAN	Wireless Local Area Network
WSN	Wireless Sensor Network
WWAN	Wireless Wide Area Network
4G	Fourth-generation mobile
5G	Fifth-generation mobile