The State of Affairs in Internet of Things Research

Nomusa Dlodlo, Thato Foko, Promise Mvelase, and Sizakele Mathaba
CSIR Meraka Institute, Pretoria, South Africa
ndlodlo@csir.co.za
tfoko@csir.co.za
pmvelase@csir.co.za
smathaba@csir.co.za

Abstract: With the Internet of Things (IoT) being a new research area, the work that is going on worldwide in this field is disjoint. The picture is not clear on who is doing what and where, thus making it difficult not only for newcomers into this field to define their space and also engage with potential collaboration partners, but also for the relatively established researchers as well to gain the necessary support in their work. There is a massive increase in the amount of data that is generated globally. This data is traditionally generated by a number of different autonomous devices. The IoT is about interfacing these autonomous devices to communicate without human intervention and generate integrated data. Intelligence is then required to process this integrated data and make it available to the humans for decision-making. If advantage is to be taken of IoT technologies, the need therefore arises to gain sufficient information that will be an impetus to further research on IoT and open the way to collaborations among the various researchers. This paper documents the international research that is going on in the area of IoT. It shows the main role players and the research territory they operate in. It also documents future research trends. The question that this research answers therefore is, "Who are the main role players in IoT research internationally, in which research space do they operate and how their work is shaping the future of IoT research?" The research is a qualitative study. A number of IoT conferences that have been held since 2008 when the first IoT conference was held in Zurich, Switzerland were identified. From the conference programs, contact details of individuals who had submitted papers or participated were identified. Emails were sent to the various stakeholders requesting information on their institutions, areas of application of IoT research and projects they were working on. Responses received also pointed to websites and publications which were then sampled to extract the relevant information. Preliminary results show that the European Union leads the pack in IoT research. Also, worldwide, institutions tend to specialise in particular aspects of IoT. Predominantly, it is the universities that are involved in IoT research as opposed to private sector institutions. Iot Research is a multidisciplinary field.

Keywords: internet of things, research, application domains, future internet

1. Introduction

The new concept of the Internet of Things (IoT) brings an opportunity for the creation of innovative applications that integrate the all too familiar traditional digital technologies. The IoT is about interfacing these autonomous devices to communicate without human intervention and generate integrated data. Intelligence is then required to process this integrated data and make it available to the humans for decision-making. In 2011, the world population reached 7 billion and the number of connected devices stood at 13 billion. By 2015 there will be over 3 times the amount of connected devices as people on the planet and 5 years later, there will be 50 billion connected devices for only 7.6 billion humans (Inspiring the internet of things, 2011). We are witnessing the return to the internet's original design. The very idea of the internet was to connect things to other things. Today there are already many things that communicate with other things, but historically they have used protocols other than the internet protocol (IP), and communication takes place over short distances, for example, in electronic locks and key cards. What is new about IoT is that communication can take place independent of location (Raunio, 2010). The original internet was about communications and then a means of delivering services. The next stage in this progression is a convergence of services with massively shared data. This is not possible without an advanced wireless and fixed infrastructure to allow access anywhere, anytime and creating an omnipresent fabric linking people and machine-to-machine communications (Future internet report, 2011).

Since IoT research is still in its infancy, there is limited literature available on the subject and so are the identities of the main role players. This research therefore documents international research that is going on in the area of IoT, the main role players and the future trends. The research raises awareness on opportunities for new players in the field to identify potential collaboration partners and map their research direction.

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Sections 2 and 3 are on the IoT definition, application domain and technologies respectively. Secion 4 is on the technologies of the internet of things. Section 5 of this paper reports on the methodology used to come up with the information. Section 6 reports on the main international role players in the IoT. Section 7 is on the potential IoT research areas as identified from the research that is currently going on. Section 8 is the discussion of the paper and Section 9 is the conclusion.

2. The internet of things

The Internet of Things (IoT) is what happens when everyday ordinary objects have inter-connected microchips inside them. These microchips help not only keep track of other objects, but many of these devices sense their surrounding and report it to other machines as well as to the humans. Also called M2M, standing for Machine to Machine, Machine to Man, Man to Machine or Machine to Mobile, the IoT intelligently connects humans, devices and systems, (Internet of Things in 2020, 2008). Analysts describe two distinct modes of communication in the IoT: thing to person and thing-to-thing communication (Raunio, 2005). Thing-to-person and person-to-thing communications encompass a number of technologies and applications, wherein people interact with things and vice versa, including remote access to objects by humans, and objects that continuously report their status, whereabouts and sensor data. Thing-to thing communications encompasses technologies and applications wherein everyday objects and infrastructure interact with the human. Objects can monitor other objects, take corrective actions and notify or prompt humans as required.

The following are examples on applications of IoT in real life. The emergence of applications of sensor networks has room for adoption by law enforcement, military, border patrol, customs, etc. Vibration sensors distributed along national borders form an effective virtual fence. From real time monitoring of water quality in the ocean through sensors connected to a buoy that sends information via the General Packet Radio Services (GPRS) network, to the monitoring of goods being shipped around the world, and smart power grids that create conditions for more rational production planning and consumption can all be achieved via microchips implanted in objects that communicate with each other. Retailers tag individual objects using radio frequency identifiers (RFID) to solve many problems all at once: accurate inventorying, loss control and the ability to support un-attended walk-through point-of-sale terminals. Innovation in logistics allows improving efficiency of processes. The warehouse becomes completely automatic with items being checked in and out and orders automatically passed to suppliers. Items in transit make intelligent decisions on routing based on information received via readers or positioning systems. Utility meters rely on machine-to-machine communications, eliminating the need for a human meter reader and allow fully-automated billing. Weather forecasting infrastructure collaborates with in-ground sensors and irrigation-control software. The irrigation system engages, based on intelligent decisions involving the level of moisture in the soil and the likelihood of precipitation. Roadside sensors detect the flow of cars that have RFID-based toll collection tags and provide traffic reports. A variety of things can report their location to owners including keys, wallets, eyeglasses, jewellery and tools. Some applications related to the IoT aren't new: toll collection tags, security access key cards, devices to track stolen cars and various types of identity tags for retail goods and livestock. Other monitoring and tracking systems have more business uses such as solving or averting problems like sending a cell-phone alert to drivers that traffic is backed up at a particular exit ramp, and increasing efficiencies such as enabling a utility to remotely switch off an electric meter in a just-vacated apartment.

The IoT in 2020: roadmap for the future (2008) defines the IoT as "things having identities and virtual personalities, operating in smart spaces using intelligent interfaces to connect and communicate within social, environmental and user contexts".

CASAGRAS defines the IoT as (Casagras, 2011): "A global network infrastructure, linking physical and virtual objects through the exploitation of data capture and communication capabilities. This infrastructure includes existing and evolving Internet and network developments. It will offer specific object-identification, sensor and connection capability as the basis for development of independent federated services and applications. These will be characterised by a high degree of autonomous data capture, event transfer, network connectivity and interoperability".

Semantically, the IoT means "A world-wide network of interconnected objects, uniquely addressable, based on standard communication protocols" (Internet of Things in 2020, 2008) .

3. The internet of things application domains

The IoT can be applied in a whole range of domains as follows (Vision and challenges for realising the IoT, 2010 and Dlodlo, 2011):

3.1 Medical technology / health

The IoT has many applications in the health sector. These may include wearable staff support systems to locate both doctor and patient in a hospital at any point in time. It may also include IoT-based knowledge systems to detect adverse reaction to drugs in patients. The combination of sensors, Wi-Fi, etc come handy in the monitoring of vital functions of the body such as temperature, blood pressure, heart rate, cholesterol levels and to stimulate the heart muscle in case of a heart attack, etc. Implantable wireless identifiers can be adopted to store health records of people with chronic illnesses. IoT applications have an enormous impact on independent living and support for aging population by detecting daily living and support using wearable and ambient sensors and monitoring chronic disease. Things can send out regular alerts, e.g. the remote monitoring of patients with health problems such as heart disease, sugar levels, blood pressure. The AIRE project of the University of Murcia in Spain designs and develops an IoT platform to support remote monitoring, detect and predict anomalies in patients with breathing problems. The same institution is working on an IoT-based personal device for diabetes therapy management in ambient-assisted living (AIRE, 2011 and AIRE, 2012). Motorola's project PERSONA is a platform to enable support in daily life activities such as risk detection in mobility (Schaller, 2008). A number of institutions from Germany, Italy and Austria are collaborating on a wearable staff support for hospital wards (Adamer, 2008).

3.2 Retail, logistics and supply chain management

Implementing the IoT in retail, logistics and supply chain management has its own advantages. Smart shelves can track the present items in real-time. Stocks can be monitored through Radio Frequency Identification (RFID) tags to alert the shop owner on when to make new orders. Fast payment solutions can be effected through tag reading check-out points. For pharmaceutical products, security and safety is of utmost importance. Tracking them through the supply chain and monitoring their status with sensors ensures a quality product to the end-user. Drugs require certain storage conditions, hence monitoring their condition in transit and on the shelves are of vital importance. IoT offers the opportunity to trace food and ingredients across the supply chain, so that recalls can be issued when quality problems arise. Researchers at the TU Dortmund and the Fraunhofer Institute for Material Flow and Logistics are working on a simulator for a large-scale baggage-handling system in which routing is controlled by a multi-agent system within an existing discrete event simulation model (Roidl, 2008). Spatial temperature deviations occur regularly during transportation of fresh food products. The University of Bremen is working on intelligent containers that calculate the shelf-life of food in transit as a function of the temperature history and sends warning messages via SMS when the shelf life drops below a warning threshold (Hiebel, 2008). Fudan University in China is researching on food traceability. A cloud computing centre in Shanghai enables tracing food across a reconstructed supply chain so that recalls can be issued when quality problems arise (Getting technical over food traceability, 2011). The SunSPOT system at the University of Murcia in Spain monitors temperature, humidity and light of goods in transit through sensors. This is to ensure freshness and suitability for consumption (Castro, 2011). Gerrnan universities use an RFID-based active sensor data logger to monitor the temperature of sensitive goods of high value in logistics (Active sensor data logger, 2012). Researchers at the Hasso-Plattner Institute are working on RFID as a basis for anti-counterfeiting by providing enhancements to existing business processes through the usage of Electronic Product Codes for identification (Integration of RFID technology in enterprise platforms, 2012)

3.3 Transport

The IoT offers a number of solutions in transport sector. Toll systems, screening of passengers and goods on aeroplanes to meet security requirements, monitoring traffic jams, and automated tracking of passengers and luggage are some of the application areas for IoT in transport. Applications in the automotive industry include the use of 'smart things" to monitor and report everything from pressure in tyres to the proximity of other vehicles. RFID technologies provide real-time data in the manufacturing and assembly of automobiles. Mobile users in vehicles are now able to communicate to other road users. There are applications to teach safe and comfortable driving by sensing the driver's behaviour and comparing it with the sensed behaviours of other motorists on the road. The aviation industry is threatened by the problem of inappropriate parts. Safety and security of the service can be achieved by protecting them from counterfeiting through RFID tags with authentication of digital signatures on the real product and wireless monitoring of parts with intelligent sensing devices. German researchers are working on car-to-car and car-to-infrastructure communication (C2X communications) to reduce road accidents and fatalities. The 30 MHz spectrum is dedicated to safety-related C2X communications (Zhang, 2008). Adaptive speed devices obtain information through GPS-enabled smart phones and calculate the driver's speed (Goralczyk, 2008). The Computer Science Department at the Waseda University in Japan are working on an application that teaches safe and comfortable driving and motivates users to change their driving behaviour by comparing with other users who drive on the same road (Kimura 2010).

3.4 Insurance

In car insurance, electronic recorders are placed in cars to record speed, acceleration and communicate the information to the insurer to assess the risk. GPS-tracking devices are used to fight car theft. Active loss prevention in transportation can be avoided through indicators and sensor-telematic devices. Early detection of hazards through sensors prevents water and fire damage. The ilab which is part of the Autoidlabs in Zurich is working on IoT applications related to insurance (Prevention within household insurance, 2012). The mobiliar emergency application allows customers to contact their insurer via their smart phone. E-bikes allow for continuous operation of GPS-based tracking devices. This tracking reduces bicycle theft and improves the safety of cyclists. Water claims caused by outdated or rusted pipes pause a problem. Early detection is the key in the prevention of water damages and related claims. Various sensors are able to detect small water leaks in rooms. SMS is sent to alert residents and automatic valves close the main water pipe.

3.5 Energy

The Bits to Energy Lab, a joint research initiative of the ETH Zurich and the University of St. Gallen in Switzerland, through its Amphiro project have developed a smart water meter that provides feedback on water consumption directly at individual faucets or shower heads. The device captures flow rate and temperature and derives the amount of water extracted, energy used and carbon dioxide emitted (The Bits to Energy Lab, 2012). The information is displayed on the basin or shower head. Through combining a smart meter with a mobile phone application, the consumption transparency is increased. Researchers at the Swedish Institute of Computer Science are working on enhancing applications to improve user awareness of energy usage. User Interfaces allow users better control over their usage (Karlgen, 2008).

3.6 Information security

The advanced research on information security and privacy project (ARES) which is funded by the Spanish Ministry of Science seeks to bring security to the information society while preserving individual rights. It focuses on three intertwined application scenarios, that is, ubiquitous computing with emphasis on wireless sensor networks and RFID, protection of critical information infrastructures and secure electronic commerce and digital content distribution, while tackling different tactical challenges in the areas of cryptology, smart cards, personal identification and biometrics, access control and authentication, network security and trust generation (ARES, 2012). The institute of Information Systems at the Humboldt-Universitat zu Berlin is working on SHARDIS – a privacy-enhanced peer-to-peer (P2P) discovery service from RFID-based production information. The idea of SHARDIS is to enhance confidentiality of the client's query against profiling by adversaries (Aletheia, 2012).

3.7 Home automation

As cheap wireless applications become abundant, the range of applications broadens. For example, smart metering is become popular for measuring energy consumption and transmitting the information to the energy provider. Sensors for temperature and humidity provide the data to automatically adjust comfort levels in a room. Researchers from the Department of Information and Communication Engineering at the University of Murcia in Spain are working on a home automation system that uses several technologies for connecting with in-house devices and an IP-based network for connecting the main home automation module with the rest of the managing and control components. The main features of the system are: a number of appliances that can be controlled, a variety of in-home networks, centralised control at a home automation module, in-home management through intuitive touch-screens, fault-tolerant design through database replication, value-addded services in local and remote gateways, remote programming of automation module and security services through several possible alarm receivers connected by several WAN technologies (Zamora-Izquierdo, 2011).

3.8 Environment monitoring

Wireless devices increasingly used in green-related applications and environmental conservation are a promising market in the future. Remote monitoring of forest fires, possibilities of earthquakes, potential floods and pollution reduce environmental risks. The wireless industry offers the opportunity to monitor petroleum personnel in critical situations, the tracking of containers and the detection of gas and oil leaks as a way of reducing the risk of accidents. The IBM Research Lab is working on projects centred around the smart planet using mobile enterprise systems. The IoT systems introduce smarter transportation and smarter buildings that reduce energy consumption and greenhouse emissions (Smart Planet, 2012). Scientists from the Urban and Civil Engineering Department at Ibaraki University and Fukuyama Consultants in Japan are working in wireless sensor integrated circuit tags to collect and visualise ground environmental information through microscopic vibrartion and tilt change of ground. This information is helpful for the prevention of disasters (Saitou, 2010).

3.9 Manufacturing

By linking items with embedded smart devices or through unique identifiers that can interact with an intelligent supporting network infrastructure, production processes can be optimised. The iPack Centre is a VINNOVA Centre of excellence established at KTH and funded jointly by VINNOVA, KTH and industrial partners. The centre is a multidisciplinary research platform that establishes collaborations between Swedish forest products industry, electronic industry and bio-medical industry in the area of intelligent paper and packaging for biomedical applications. The centre develops core technologies for heterogeneous integration of biomedical sensors, energy supplies, computing and wireless communications on fibre-based packaging and paper boards, for innovative products such as smart bio-paper, intelligent pharmaceutical packaging and storage, intelligent patient monitoring devices. The research explores multi-disciplinary innovations encompassing self-powered, ultra low-cost wireless links, paper-based bio-medical sensors, printed energy cells and interactive paper functions, low-cost manufacturing and integration technologies as well as manufacturability aspects (iPack VNN Excellence Centre, 2012)

3.10 Agriculture

During outbreak of disease, real-time detection of the movement of animals through RFID tags becomes handy.To improve the efficiency of agricultural production, agricultural mechanisation is a key measure. The Chinese have developed an intelligent scheduling platform for agricultural machinery working with integrated ICT such as the internet, mobile phone, fixed phone, satellite navigation systems, cloud computing to implement the guidance and service of administration departments to agricultural mechanisation production, promote the restricted flow of machinery countrywide and improve its utilisation. The platform commands and dispatches farm machines, executes tillage, cultivation and harvest according to factors such as crop maturity time, weather, farm machine distribution, etc. It can realise functions including inquiry of farm machine positions, tract review, information reception and release, remote failure diagnosis, and measuring farmland area and estimation of crop yields (Zhiguo, 2011).

3.11 Education

IoT can enable interaction with physical spaces for learning purposes or communication. Researchers from the Department of Computer Science at the University of Waseda in Japan are working on an augmented calligraphy system that aims at supporting a calligraphy learner's self-training process by giving feedback. The system monitors the learner's posture by a web camera and notifies them if the posture moves into a bad shape. The system also supports a grading feature so that the learner can improve calligraphy writing skill. The web camera captures the images written on paper and their shape is recognised with OpenCV library (Shichinohe, 2010).

3.12 Telecommunications

The IoT creates the possibility of merging different technologies such as Global System for Mobile Communications (GSM), Near-Field Communications (NFC), Bluetooth, Global Positioning Systems (GPS), sensor networks, etc to create new services. The border between IoT and telecommunications blurs in the long term.

4. Technologies of the internet of things

A number of technologies can be identified by analysing a wide range of literature including (Inspiring the internet of things, 2011):

4.1 RFID

Radio-frequency identification (RFID) uses radio waves to identify items. In contrast to bar codes, RFID tags can be read away from the line of sight. They track items in real-time to yield important information about their location and status. Early applications of RFID include automatic highway toll collection, keeping track of entire inventory, supply-chain management for large retailers, prevention of counterfeiting in pharmaceuticals, and for patient monitoring in e-health. RFID tags are being implanted under the skin for medical purposes, e-government applications such as in drivers' licences and passports and RFID-enabled phones are some of the applications.

4.2 Sensor networks

To detect changes in the physical status of things is also essential for recording changes in the environment. In this regard, sensors play a pivotal role in bridging the gap between physical and virtual worlds, and enabling things to respond to changes in their physical environment, generating information and raising awareness about the context. Sensor networks need not be connected to the Internet and often reside in remote sites, vehicles and buildings having no Internet connection.

4.3 Microcontrollers

Microcontrollers are computer chips that are designed to be embedded into objects. Embedded intelligence in things distributes processing power in the network, and empowers things and devices in the network to take independent decisions.

4.4 Protocols

Machine-to-machine interfaces and protocols of electronic communication set the rules of engagement for two or more nodes of a network. Internet Protocol (IP) has become the standard for all data communication and it is therefore easy to move things over the Internet. Examples of protocols that can be used in low-power radio for communication are: Link Layer, ISA 100A, Wireless HART, ZigBee and IPv6. The Internet protocol for lower-power radio IPv6 plays a big role in the IoT. The advantage of IPv6 is that it meets the challenges of different existing systems having to work together. Because this interoperability is possible, the system of objects connected via the Internet can develop the same way that the current Internet developed. The version of IP currently in use, IPv4, supports only 4.3 billion unique addresses- a fraction of what is required to assign a name and location to everyone and everything.

4.5 Biometrics

Biometrics enables technology to recognise people and other living things, rather than inanimate objects. Connected everyday objects could recognise authorised users by means of fingerprint, voice print, iris scan or other biometric technology.

4.6 Machine vision

Machine vision can be a channel for delivering the same type of information that RFIDs enable. Machine vision is an approach that can monitor objects having no on-board sensors, controllers or wireless interfaces. For example, cameras on typical cell phones can capture images of objects; using image-processing algorithms, distant servers can identify such objects and report information about them. Smart components are able to execute different sets of actions, according to their surroundings and the tasks they are designed for. For instance, devices are able to direct their transport, adapt to their respective environments, self configure, self-maintain, self-repair and eventually even play an active role in their disposal.

4.7 Actuators

Actuators detect an incoming signal and respond by changing something in the environment. Actuators such as motors, pneumatics and hydraulics can move objects and pump fluids. A relay, for example, is an actuator that toggles a mechanical switch, and can thus cause a good number of responses to occur such as enabling illumination, heating system, audible alarm and so on.

4.8 Location technologies

Location technology helps people and machines find things and determines their physical whereabouts. Sensors play a role, but that approach does not satisfy practical needs for geolocation resulting in the rise of wireless approaches including GPS and cellular towers. Radar, lidar and sonar can detect relative location of things, depending on their electromagnetic, optical and acoustic properties. Some things transmit their own radio, light and/or sound in order to disclose their whereabouts to people and machines. In the automatic identification of tagged products in order to quickly look up information or initiate a specific action, using bar codes for linking real-world objects to virtual information has a number of drawbacks when compared to an RFID-enabled feature with corresponding mobile RFID readers, such as Near Field Communication(NFC)-enabled mobile phones. Near Field Communication is a short-range wireless connectivity standard that enables communication between devices when they are brought within a few centimetres of each other through magnetic induction.

4.9 Bar codes

A bar code is an optical representation of machine-readable data and can be seen on the majority of products that are on sale in the retail industry to speed up the checkout process. These linear symbologies or so-called one-dimensional (1D) barcodes represent data in vertical parallel lines with varying space and line width. A lesser well-known two-dimensional (2D) barcode or matrix code is also an optical representation resembling something like a crossword puzzle of even more machine-readable data and can normally be seen on larger packaging containers to assist with warehouse logistics and quality control. Examples of matrix codes include QR Code, Data Matrix code and Semacode. QR Code is derived from Quick Response as the creator intended to allow its contents to be decoded at high speed. A Data Matrix code is made up of a two-dimensional matrix code consisting of black and white square modules arranged in either a square or rectangular pattern. The information to be encoded can be text or raw data. The code can be read quickly by a scanner which allows the media to be tracked, e.g., on a parcel. Semacode is machine-readable ISO/IEC 16022 data matrix symbols which encode URLs. It is primarily aimed at being used with cellular phones which have built-in cameras. A URL can be converted into a type of barcode resembling a crossword puzzle, which is called a “tag”. Tags can be quickly captured with a mobile phone’s camera and decoded with a reader application to obtain a web site address. This address can then be accessed via the phone’s browser.

4.10 Ambient technologies

Ambient technologies refer to electronic environments that are sensitive and responsive to the presence of people. In an ambient intelligence world, devices work in concert to support people in carrying out their everyday life activities in easy , natural way using information and intelligence that is hidden
in the network connecting these devices. The ambient intelligence paradigm builds upon pervasive computing, ubiquitous computing, profiling practices and human-centric computer interaction design. It is characterised by systems that are:

- Embedded: many networked devices are integrated into the environment
- Context-aware: these devices can recognise you and your situational context
- Personalised: they can be tailored to your needs
- Adaptive: they can change in response to you
- Anticipatory: they can anticipate your desires without conscious mediation

5. Methodology

5.1 Purpose of research

The aim of this research was to document the international IoT research trends and landscape. The questions that this research asks are:

- Who are the main role players in IoT research internationally?
- In what research space does each of the role players operate?
- What patterns and trends are emerging in IoT research?
- How is the work of the role players shaping the future of IoT research?

5.2 Data collection

This research constitutes a qualitative study. Qualitative studies base their accounts on qualitative information, i.e., words, sentences and narratives (Blumberg, et.al, 2008). E-mails were sent to the various stakeholders involved in IoT research requesting information on their institutions, areas of application of IoT research and a brief overview of the projects they were working on. The responses received pointed to organisation websites and publications in most cases and these were accessed to extract the relevant information. These responses were captured as country specific IoT research trends to show the main actors in the field. The answers to these questions formed the underlying base to a literature survey and document analysis. The literature search was also conducted to fill in the gaps in the identified landscape and trends. Publications were downloaded which gave an indication of what research was going on in some of the institutions where there were no respondents.

5.3 Profile of respondents

The researchers identified a number of IoT conferences that have been held since 2008 when the first internet of things conference was held. These conferences were:

- The First International Conference, IOT 2008, Zurich, Switzerland, March 26-28, 2008
- The Internet of Things Europe 2009: Emerging technologies for the Future, Sofitel, Brussels Europe Hotel, May 7-8, 2009
- The 2nd Annual Internet of Things Europe 2010: A roadmap for Europe, Crowne Plaza Brussels – Le Palace, June 1-2, 2010
- RFID Systech 2010, University Castilla-La mancha, Ciudad, Spain, June 15-16, 2010
- Internet of Things 2010 Conference, Tokyo, Japan, November 29-December 1, 2010
- The 3rd Annual Internet of Things Europe Conference, Central Brussels, June 28-29, 2011,
- Internet of Things Conference, China 2011, Shanghai World Financial Centre, June 16-17, 2011

From the conference programs, names of individuals who had submitted papers at these conferences were identified. An internet search yielded their contact details. Of the 350 emails sent out, 37 responses were received from 12 countries. These countries include Spain, Germany, Switzerland, USA, Greece, United Kingdom, Taiwan, Brazil, China, Italy, France and Sweden. The institutions that are active participants are given in the analysis in Section 5.

5.4 Analysis

The information collected was classified according to country, domain of application, institution involved, research conducted by the institution and the various applications of the research work. Examples of domains of application would be location and tracking, education, security, ambient assisted living, intelligent transport, smart homes and planets, vehicular communications, retail and logistics, health, business, regulatory, legal, energy and insurance. Examples of applications of the research would be monitoring forest fires, locating goods in transit, remote monitoring of a patient's health, for example.

5.5 Study protocol

The development of a study protocol enabled the study to improve and achieve reliability.

Purpose	Study issues	Effects
Identify respondents	The respondents should be individuals and organisations who are active in the field of IoT research. IoT conferences were selected as sources of identification of such individuals and organisations, since participating in such conferences is an indicator of involvement in IoT research	The study targets individuals and organisations that are already involved in IoT research
Identify role of researcher	The role of the research is to identify respondents, solicit information through e-mail and conduct a literature survey.	The researcher is a person who is involved in IoT research. This is because they are in a better position to understand the field and give a proper analysis of concepts
Ensure optimum response from individuals and organisations is achieved	Effort is made to obtain an optimum response in terms of numbers of respondents by making follow-ups to requests for information where necessary.	The respondents' responses are recorded and analysed.
Ensure a comprehensive literature survey to identify trends and patterns is conducted	Ensuring a comprehensive literature survey leads to the production of a comprehensive analysis of trends and patterns	A technical report on literature is produced and analyses given

6. Role players in the internet of things

The preliminary results show Spain, Germany, Switzerland and Japan as the leading role players in the IoT industry (Dlodlo, et.al., 2011). Other countries are Austria, Czech Republic, USA, France, Taiwan, Iran, Denmark, United Kingdom, Finland, Netherlands, China, Brazil, Sweden, Italy, Greece, Korea and Norway as players to a lesser extent. Overall, Europe is the leading continent and supports IoT research through European Union Framework funding for consortia.

Spanish institutions are involved in wireless sensor systems for early forest fire detection, RFID transmitters to locate and trace personal assets in indoor and industrial processes and inventory control, NFC to enable interaction with physical spaces for learning and communication, human body monitoring using sensor fusion and neuro-imaging and home automation systems for controlling in-house devices. The main role players in the Spanish IoT space are the University of Zaragoza, Escuela Technica Superior de Inginieria Informatica, University of Girona, Polytechnic University of Cartagena, Universidad de Castilla la mancha, University of Diesto, University of Malaga and the University of Murcia.

German institutions are working on RFID sensor data loggers to monitor the temperature of sensitive goods in logistics and handling of blood products in hospitals, C2X communications to reduce road accidents, sensors for environmental and user condition monitoring, wearable staff support systems for hospital rounds and middleware for facility management applications. The main role players in the German IoT space are the Hasso-Plattner Institute, University of Applied Sciences-Offenburg, Friederich-Alexander University of Erlangen-Nuremberg, University of Applied Science Bonn-Rhein, Fraunhofer Centre for Intelligent objects, Fraunhofer Centre for Integrated Circuits, Fraunhofer Institute for Material Flow and Logistics, University of Stuttgart, Technische University of Berlin, University of Bremen, Motorola, University of Bremen, Humboldt University zu Berlin, Technische University of Dresden, University of Karlsruhe, Hanover University, TU Munchen institute, SAP Research, Otto-von-Guencke University, Fraunhofer Geselleschaft, Technische University Darmstadt, Deutsche Telekom Lab and the Technische University Braunschweig.

Researchers in Switzerland are working on low-cost RFID tags for anti-counterfeiting, integration of shop-floor devices with enterprise systems, remote product authentication using NFC-enabled mobile phones, object recognition through visual features, global geometry and GPS location, sensor-based issuing policy on product quality in the perishable supply chain, legal aspects of IoT such as governance, security and privacy, emotive environments, smart meters in energy conservation, mobile systems for insurance claims and communications, and web connectivity for low-power resource-constrained devices. The main role players are ETH Zurich, SAP AG St. Gallen, University of St. Gallen, Swiss Federal Institute of Technology, Zurich Research Laboratory and IBM Research GmbH,.

Researchers in Japan are working on intelligent vehicular communication systems that collect and analyse data from users and calculate optimised driving on the road, wireless sensor integrated circuit tags to collect and visualise ground environment information through microscopic vibration and tilt change of ground, augmented calligraphy system that supports a calligraphy learner's self training process by giving feedback, and wearable computing environment for location services. The main role players are Waseda University, Ibaraki University, Tokyo Denki University, University of Tokyo and Keio University.

French researchers are working on a large scale EPC global network in which only one ONS root will exist in Europe and will be managed on a shared basis, security in vehicular networks, systems to track patients, medical personnel, drugs and equipment and a smart planet using mobile enterprise systems. The main role players are GSI France, France Telecom Group, Telecom ParisTech, AFNIC, RFID European lab.

Researchers in the USA are working on efficient cryptographic techniques to speed up integrity verification and detection of integrity corruptions in vehicular networks and business policies and government policies that shape the IoT. Researchers in the UK are working on sensor-based systems for monitoring workers exposure to vibration in order to reduce incidents of "vibration white finger" at construction sites, smart cities, ambient intelligent systems in speech recognition and natural language processing. Norwegian researchers are working on wireless smart applications in automotives, aeronautics, telecoms, medicine and logistics, RFID technologies for ambient systems, vehicle identification systems and embedded systems for electric vehicles. One of the main Norwegian role players in IoT is SINTEF.

Institutions tend to specialise in a particular aspect of IoT. The following are just a sampled example from a large range of institutions. Hitachi Europe specialises on smart cities, ETH Zurich's institute of pervasive computing specialises in smart objects. The IBM Austin research lab is working on the smart planet, while the Centre for Intelligent Objects at the Fraunhofer Institute is working on intelligent objects. In the area of logistics and production, the main role players are the Fraunhofer Institute for Material Flow and Logistics in Germany, the Group for the Automation of Production and Logistics (AUTOLOG) at the University of Castilla-la Mancha in Spain and the University of Bremen. The main role players in IoT in energy are the Escola Polytechnica University of Sao Paulo, with SAP Germany and the Department of Engineering at the University of Padova in Italy working on smart grids and energy-efficient buildings. In the area of e-health the Signals Processing and Biomedical Research Group at the University of Granada is working on human body monitoring, while the Intelligent Systems and Telematic Engineering Group at the University of Marcia in Spain is working on remote monitoring of patients. For IoT in security is the Institute for Information Systems in Humboldt University in Germany, the Network, Information and Computer Security Lab at the University of Malaga in Spain, the Department of Information and Communication System Engineering: information security at the University of Aegen in Greece and the Hasso-Plattner Institute of IT Systems Engineering in Germany. The University of Zurich Switzerland specialises in the legal aspects of IoT such as security governance and privacy.

The EU Framework has/and is still funding a number of projects in the area of IoT (EU framework projects, 2011). These projects are run by consortia of EU countries. The cooperating objects network of excellence (CONET) consists of 12 members. Cooperating objects consist of embedded computing devices equipped with communication as well as sensing or actuation capabilities that are able to cooperate and organise themselves autonomously into networks to achieve a common task. The ability to communicate and interact with other objects and/or the environment is a major prerequisite. These devices interact with their environment either by monitoring it (sensors) or by changing it (actuators), process the data and communicate to others.

The SOCRADES integrated project creates new methodologies, technologies and tools for the modelling, design, implementation and operation of networked systems made up of smarter embedded devices. Achieving enhanced system intelligence by co-operation of smart embedded devices pursuing a common goal is relevant in many types of perception and control system environments. In general, such devices with embedded intelligence and sensing/actuating capabilities are heterogeneous, yet they need to interact seamlessly and intensively over a wired or wireless network.

The objective of the Biometric Access Control for Networked and e-commerce applications (BANCA) project is to develop and implement a complete secured system with enhanced identification, authentication and access control schemes for applications over the Internet tele-working and web-banking services.

Power Line Communication (PLC) has the disadvantage of low speed, functionality and high cost. The 6POWER project adapts and integrates products, applications and services that run with IPv6 and related protocols over Power Line, providing high speeds at low cost.

The INTELLECT project develops an electronic shop system including an online configuration module for products which is represented by 3D / Virtual Reality techniques and advanced user assistance and advice to improve the business opportunities for service providers and consultants as well as for manufacturers, wholesalers, sellers and customers.

Fi-WARE is a project working on an open architecture of a novel service infrastructure, building upon generic and reusable building blocks to support the Future Internet. SMARTCODE on the other hand is smart control of demand for consumption & supply to enable balanced, energy-positive buildings and neighbourhoods. The ELLIOT project aims to develop an IoT experiential platform where users/citizens are directly involved in co-creating, exploring and experimenting new ideas, concepts and technological artefacts related to IoT applications and services. IOT@WORK aims at developing the technologies required to enable IOT-based applications and processes in the manufacturing domain.

SMARTSANTANDER proposes a unique scale experimental research facility in support of typical applications and services for a smart city. The NOBEL project builds an energy brokerage system with which individual energy consumers can communicate their energy needs directly with both large-scale and small-scale energy producers, thereby making energy use more efficient. The brokerage system will use a middleware system to communicate energy consumption data and will use IPv6 technology to interconnect the middleware with sensors and energy meters on individual devices.

The EBBITS project aims to develop architecture, technologies and processes, which allow businesses to semantically integrate IoT into mainstream enterprise systems and support interoperable real-world, on-line end-to-end business applications. The lighthouse project Internet of Things Architecture IoT-A proposes the creation of an architectural reference model for the IoT as well as the definition of a set of key building blocks to lay the foundation for a ubiquitous IoT. Internet of Things Initiative-IOT-I aims at creating a joint strategic and technical vision of the IOT in Europe that encompasses the currently fragmented sectors. It will provide semantic resolution to the IoT and hence present a bridge between enterprise applications, people, services and the physical world, using information generated by tags, sensors, and other devices and performing actions on the real-world. IOT.EST is the IoT environment for service creation and testing. Interoperability between silo solutions and technologies used in disjoint sectors is important. The project integrates new types of services and generate new business opportunities through dynamic service creation environment that gathers and exploits data and information from sensors and actuators that use different communication technologies/formats

7. Potential research areas in IOT

Potential research areas in the IoT are (Dlodlo, 2011):

Governance: Without a standardised approach it is likely that a proliferation of architectures, identification schemes, protocols and frequencies will develop side by side, each one dedicated to a particular and separate use. This will lead to the fragmentation of IoT. Interoperability is a necessity, and inter-tag communication is a precondition

Ubiquitous networks: There are 2 major challenges to guarantee seamless network access: the first is that today different networks co-exist; the other is the sheer size of the IoT. Issues such as address restriction, automatic address set-up, security functions such as authentication and encryption and 18 multicast functions to deliver voice and video have to be overcome by technological developments

Legislation, regulation and policy: A clear legislative framework ensuring the right of privacy and security level for all users must be implemented internationally.

Intelligent objects: The amount of intelligence that the objects in the IoT will need to have and if, how and in which cases this intelligence is distributed or centralised becomes a key factor. Interactive standards are associated with behavioural changes. Take, for example, a case in which an interactive device is implanted in the human body to deliver the right medicine at the right time. Intelligent nodes can be integrated into hybrid wireless networks and used in applications like monitoring of buildings and the environment, home automation and locating systems.

Security of the IoT: A major component of IoT is security and privacy of data.

Software and services: The development of the IoT is expected to come along with a new range of user-centric services, based on the interaction of day-to-day processes with the network. The delivery of those services will be frequently seamless for the user, requiring no specific interaction with them. The business model for the delivery of those services will require the interaction and collaboration of several organisations. In particular “event-driven” middleware and sensor “dynamic service capability declaration” is required.

Virtual and physical objects fusion: Applications may process data coming from both a 3D virtual world and from the real environment. New (merged) information processing management tools may be needed, for instance search engines capable of processing data from the physical and virtual worlds.

Geotagging / geocaching: Geographic information systems (GIS) play a role in locating things. An Internet of Places (IoP) can arise as more systems recognise where they are and can access GIS.

Biometrics: Identification of individuals combined with databases of information about people could have synergies with personal geolocation, enabling the IoT.

Machine vision: Image recognition could evolve towards characterising things’ behaviours not just their identities.

Robotics: Connected everyday objects and sensor networks are key enablers for robots. Onboard wireless communications may be critical for interconnecting robot systems.

Augmented reality: Researchers aim to enable systems to report context-sensitive information when people come into proximity with other people, places and things. Such information could appear on cell phone displays, wearable near-eye displays, head-up displays in vehicles, or using other convenient means.

Mirror worlds: Electronic media – whether a simple display or a complex virtual-reality platform – can help people visualise distant events and situations. Software can use icons and other abstractions to help visualise the location of real world objects. Objects including vehicles, personnel and equipment can self-report via various types of sensors, machine vision and other technologies.

Telepresence: Persons at a distance can access information gathered by an object and can control the actions of distant objects.

Tangible user interfaces: People can control technology by manipulating everyday objects rather than being limited to using keyboards, mice, displays and dedicated control surfaces.

QR Codes: Applications of QR code in the IoT are possible. Mobi.Ubiq provides mobile application and a web service that enables you to scan, discover and share objects with RFID or barcode tags. Based on the identified object, information and services become available. Mobi.Ubiq is a framework to connect everyday objects and supports building and interacting with the IoT.

Mobile devices and the IoT: Combining physical mobile interactions occurs when mobile devices are used to interact with physical objects in the IoT.

Mash-up applications – These are new services requiring appropriate levels of interface standardisation and interoperability, of dynamic configuration capability, an increased level of trust and associated information security supporting person privacy.

Business models in the IoT: With the advent of this technology various kinds of business models emerge.

Communication issues: These include antennae integration on chip, smart antennas, API – standardised and secure, modulation schemes, transmission and speed

Interoperability issues: These cover multi-tag integration, inter-tag communication, centralised and decentralised, with other communication networks.

8. Discussion

The preliminary results show Spain, Germany, Switzerland and Japan as the leading role players in the IoT industry. Other countries are Austria, Czech Republic, USA, France, Taiwan, Iran, Denmark, United Kingdom, Finland, Netherlands, China, Brazil, Sweden, Italy, Greece, Korea and Norway as players to a lesser extent. Overall, Europe is the leading continent and supports and spearheads IoT research through European Union Framework funding for consortia. China is also a strong contender, although there is little academic publication on their work. China though has a substantial number of IoT applications on the ground. Since this research has a foundation on literature that is available in the public domain, we cannot assume that the countries that do not appear on this list are not participating in any IoT research. It may be that they are keeping their work to their chests. The research also shows that it is the universities predominantly that are involved in IoT research as opposed to private sector companies. Universities are known to be areas that generate knowledge for the public domain as opposed to private companies whose main aim is to generate income from whatever they are involved in. It is not surprising therefore that private companies do not publish their work in the public domain.

IoT research can be approached from both a socio-economic and a technology research perspective. From a socio-economic perspective, social, legal, ethical, business, cultural security, privacy and regulatory aspects of IoT can be visited. The technologies that support the IoT are what we are traditionally familiar with, and what our education institutions teach. These technologies include wireless sensor networks, robotics, vision recognition, smart tags, microcontrollers, mobile devices, near-field communications, RFIDs, bar codes, social networks, EPCglobal networks, cloud computing, CoAP, 6LowPAN to name but a few. The question therefore is why these technologies should be rebranded the IoT, when they have been in existence in the market for a long time. To differentiate IoT from the traditional technologies, IoT research should therefore be in the form of integrating the traditional technologies to produce what is called IoT applications. Traditional technologies existing in isolation from one another cannot be branded the IoT. A standard definition of the IoT is still outstanding, judging from the varied definitions that are given in literature.
If the IoT is about adaptation of physical objects to be able to communicate via the Internet, then to design IoT applications a whole range of experts ranging from electrical and electronic engineers, computer scientists, programmers, information systems specialists, human science experts and creative specialists should constitute the team. IoT research is multidisciplinary in nature.

9. Conclusion

The study investigated who the current role players in the IoT were, what they are involved in and how this shapes the future direction of IoT research. IoT is an exciting and innovative field that talks about integrating various traditional technologies to produce new applications. Therefore it is about transforming the expert from one that is focused on one area of expertise to an all rounder that understands the various technologies and how they can be brought together. The research raises an awareness on the availability of the focused expertise from an international perspective, so that collaboration can be encouraged to produce these applications. Because IoT is a new field that is about redefining the role of the researcher, it also calls for a redefinition of the direction that current traditional research takes. It also opens opportunities for collaboration in multidisciplinary research. The opportunities for collaboration should take advantage of the potential of integrating technologies in various domains. There are already leaders in the field and it is just a question of identifying after them the potential research areas in IoT that one can fit into. The EU is leading the pack because the organisation has ploughed resources in this direction. A few years down the line, the state of affairs is likely to change, with more role players coming in. This research is limited to the literature that is available currently, and as more role players publish their work the landscape will definitely change.

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