The Internet of Things:

Between the Revolution of the Internet and the Metamorphosis of Objects

By Gérald Santucci

Table of contents

"The Internet of Things has the potential to change the world, just as the Internet did. Maybe even more so."

Kevin Ashton, 2009

"And men got dreaming. Shouldn't there be a network that made all my devices collaborate at all times, converse spontaneously among themselves and with the rest of the world, and all together make up a kind of single virtual computer – the sum of their respective intelligence, knowledge and know how?"

Rafi Haladjian, 2005

"Society is now created for technological, rather than for human, requirements. And that's where tragedy begins."

C. Virgil Gheorghiu, The Twenty-Fifth Hour, 1950

"Because of the crisis, doomsday is postponed"

La Gueule Ouverte, May 1968

After the World Wide Web (the 1990's) and the mobile Internet (the 2000's), we are now heading to the third and potentially most "disruptive"[1] phase of the Internet revolution – the "Internet of Things". The Internet of Things links the objects of the real world with the virtual world, thus enabling anytime, anyplace connectivity for anything and not only for anyone. It refers to a world where physical objects and beings, as well as virtual data and environments, all interact with each other in the same space and time.

1. Origin of the concept of "Internet of Things"

1.1. MIT Auto-ID Center

The phrase "Internet of Things" was coined some 10 years ago by the founders of the original MIT Auto-ID Center, with special mention to Kevin Ashton in 1999[2] and David L. Brock in 2001[3]. The term "Auto-ID" refers to any broad class of identification technologies used in industry to automate, reduce errors, and increase efficiency. These technologies include bar codes, smart cards, sensors, voice recognition, and biometrics. But since 2003 the Auto-ID technology on the main stage has been Radio Frequency Identification (RFID).

The climax of the Auto-ID Center reputation occurred in September 2003, when the EPC (Electronic Product Code) Executive Symposium taking place in Chicago (Illinois, USA) marked the official launch of the EPC Network – an open technology infrastructure allowing computers to automatically identify man-made objects and track them as they flow from the plant to distribution centre to store shelves. The Symposium, supported then by more than 90 major companies from around the world – representing food, consumer goods, retail, transportation and pharmaceuticals industries, among others – highlighted RFID deemed to become a key enabling technology for economic growth in the next fifty years. Considering the Symposium in historic terms, Kevin Ashton foretold a shift from computer information processing to computer sensing.

A few weeks after the Symposium, in October 2003, the MIT Auto-ID Center was re-christened as Cambridge Auto-ID Lab when it was closed and split into a research arm – the Auto-ID Labs – and a commercial arm – EPCglobal, a joint venture between UCC and EAN.

The goal of the Auto-ID Labs is to develop a network connecting computers to objects – not just the hardware (RFID tags and readers) or the software to run the network, but actually everything that is needed to create an Internet of Things, including affordable hardware, network software and protocols, and languages for describing objects in ways computers can understand. It is important to note that the Auto-ID Labs is not seeking to create another

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1 *The term "disruptive technology" was coined by Clayton M. Christensen and introduced in his 1995 article Disruptive Technologies: Catching the Wave, which he co-wrote with Joseph L. Bower. Ref. Harvard Business Review, January-February 1995.*

2 "*I could be wrong, but I'm fairly sure the phrase 'Internet of Things' started life as the title of a presentation I made at Procter & Gamble (P&G) in 1999*", Kevin Ashton, RFID Journal, 22 June 2009.

3 David L. Brock, MIT Auto-ID Center, MIT-AUTOID-WH-002, "The Electronic Product Code", January 2001.

global network but rather to develop the elements built on top of the Internet[4] that would enable tracking items and sharing information over the Internet.

1.2. When Internet of Things leaves the lab to come in broad daylight

Among the first papers of general interest on the Internet of Things, those mentioned below marked the beginning of a new era for commerce and industry. The Internet of Things is considered then as the mere extension of Radio Frequency Identification where *"RFID is kind of the amoeba of the wireless computing world"* (Kevin Ashton). But the phrase "Internet of Things" points out a vision of the machines of the future: in the nineteenth century, machines learned *to do*; in the twentieth century, they learned *to think*; and in the twenty-first century, they are learning *to perceive* – they actually sense and respond.

- "The Internet of Things", by Sean Dodson, The Guardian, 9 October 2003.[5]
- "Toward a Global Internet of Things", by Steve Meloan, Sun Microsystems, 11 November 2003.[6] It heralded that "*With the official release of the Electronic Product Code Network, we are about to see the Internet of Things paradigm enter the big time – the world of mainstream commerce*". Sun Microsystems argued of course that with its notion that "The Network is the Computer", it was uniquely positioned to play a leading role in the Auto-ID revolution, especially with respect to security, scalability and cross-platform compatibility.
- "A Machine-to-Machine Internet of Things", Business Week, 26 April 2004.
- "The Internet of Things", by Neil Gershenfeld, Raffi Krikorian and Danny Cohen, Scientific American Magazine, October 2004 – *"The principles that gave rise to the Internet are now leading to a new kind of network of everyday devices."*
- "The Internet of Things: Start-ups jump into next big thing: tiny networked chips", by Robert Weisman, The Boston Globe, 25 October 2004.[7]

1.3. International Telecommunications Union (ITU)

The concept of "Internet of Things" came into limelight in 2005 when the International Telecommunications Union published the first report on the subject[8]. At that time, Lara Srivastava, ITU's Strategy and Policy Unit, said: "*It's safe to say that technology today is*

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4 More specifically the Electronic Product Code (which gives each item a unique number), the Object Name Service (which points a computer to an address on the Internet where information about a product is stored), the XML-based Physical Markup Language (which enables computers to gather information and act on it), and the software technology called Savant (which allows to manage and move information in a way that doesn't overload existing corporate and public networks).

5 http://www.guardian.co.uk/technology/2003/oct/09/shopping.newmedia

6 http://java.sun.com/developer/technicalArticles/Ecommerce/rfid/. This article heralded that "*With the official release of the Electronic Product Code Network, we are about to see the Internet of Things paradigm enter the big time – the world of mainstream commerce*". Sun Microsystems argued that with its notion that "The Network is the Computer", it was uniquely positioned to play a leading role in the Auto-ID revolution, especially with respect to security, scalability and cross-platform compatibility.

7 http://www.boston.com/business/technology/articles/2004/10/25/the_internet_of_things/

8 "The Internet of Things", ITU, November 2005.

more pervasive than we would ever have imagined possible 10 years ago. Similarly, 10 years from now things will continue in this general direction. That's what these new technologies are telling us."

The ITU report adopts a comprehensive and holistic approach by suggesting that the Internet of Things will connect the world's objects in both a sensory and intelligent manner through combining technological developments in item identification ("tagging things"), sensors and wireless sensor networks ("feeling things"), embedded systems ("thinking things") and nanotechnology ("shrinking things"). By addressing ICT and nanotechnology together, this report touches on the concept of "convergent technologies" brought up by the U.S. National Science Foundation (NSF) in its 2002 report for achieving "a tremendous improvement in human abilities, societal outcomes, the nation's productivity, and the quality of life"[9]. At the same time, the ITU report identifies the most important challenges that need to be tackled for fully exploiting the potential of the Internet of Things – standardisation and harmonisation, privacy, and socio-ethical issues.

2. Development of the Internet of Things

Today, there are roughly 1.5 billion Internet-enabled PCs and over 1 billion Internet-enabled cell phones. The present "Internet of PCs" will move towards an "Internet of Things" in which 50 to 100 billion devices will be connected to the Internet by 2020. Some projections indicate that in the same year, the number of mobile machine sessions will be 30 times higher than the number of mobile person sessions. If we consider not only machine-to-machine communications but communications among all kinds of objects, then the potential number of objects to be connected to the Internet arises to 100,000 billion[10]! In such a new paradigm, networked objects are so many that they blur the line between bits and atoms. Several authors have created new concepts to apprehend the Internet of Things paradigm. For example, Julian Bleecker speaks of *blogjects* to describe objects that blog[11], Bruce Sterling speaks of *spimes* to portray location-aware, environment-aware, self-logging, self-documenting, uniquely identified objects that provide a lot of data about themselves and their environment, Adam Greenfield speaks of the "informational shadows" of networked objects, Rafi Haladjian speaks of the *Pervasive Network* connecting any type of machine, permanently and seamlessly, both indoors and outdoors, at high speed and at an imperceptible cost, but not with just anyone/anything.

All specialists agree that the challenges of the Internet of Things will be manifold and far-reaching. We will try here to identify some of these challenges by considering the perspectives of Research, Industry, and Central and Local Government. Obviously, many initiatives involve Research, Industry and Government at the same time like, for instance, the

9 NSF/DOC-sponsored Report, "Converging Technologies for Improving Human Performance: Nanotechnology, Biotechnology, Information Technology and Cognitive Science", June 2002.

10 Source: Rafi Haladjian, inventor of the communicating rabbit Nabaztag, 25 May 2009.

11 Perhaps we could speak as well of *twitterjects* if we consider that networked objects all around the world will be able to share and discover almost instantly what's happening in their environments.

three-year project, announced in February 2010, involving the U.S. National Science Foundation (NSF) and Microsoft[12].

2.1. Research perspective

Today the Auto-ID Labs form an independent network of seven academic research labs on four different continents[13] that develop new technology such as RFID and Wireless Sensor Networks (WSNs) for revolutionising global commerce and providing previously unrealisable consumer benefits.

Three of the laboratories – University of St. Gallen, ETH Zurich and MIT – organised in Zurich in 2008 the first Internet of Things Conference[14] that brought leading researchers and practitioners from both academia and industry together to facilitate sharing of applications, research results, and knowledge. The next conference will be organised at the end of 2010 in Tokyo around the theme "IoT for a Green Planet"[15] – it will explore the technical requirements and business challenges to address today's societal challenges with IoT technology: Health monitoring systems to support the aging society, distributed awareness to help predict natural disasters and react more appropriately, track and trace to help reduce traffic congestion, product lifetime information to improve recyclability, transparency of transportation to reduce carbon footprint, and more insights into various kinds of processes to improve optimisation. It is noteworthy that this conference will take place at about the same time as the 27th TRON Project Symposium on the Ubiquitous Computing Society, which is organised every year by Professor Ken Sakamura[16].

Another research perspective for the Internet of Things is given by Hewlett-Packard which has launched a ten-year mission, a Central Nervous System for the Earth, to embed up to a trillion pushpin-size sensors around the globe. By combining electronics and nanotechnology expertise, Hewlett-Packard researchers have developed "smart dust" sensors with accelerometers that are up to 1,000 times more sensitive than the commercial motion detectors used in Nintendo Wii video game controllers and some smart phones. Potential applications include buildings that manage their own energy use, bridges that sense motion and metal fatigue, cars that track traffic patterns and report potholes, and fruit and vegetable shipments that tell grocers when they ripen and begin to spoil.

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12 The goal of this project is to give American scientific researchers the Cloud Computing power to cope with exploding amounts of research data.

13 Massachusetts Institute of Technology (Cambridge, Massachusetts, USA), Keio University SFC Research Institute (Tokyo, Japan), University of Cambridge (Cambridge, UK), University of St. Gallen & ETH Zurich (Switzerland), Fudan University (Shanghai, China), Auto-ID Lab@ICU (Daejeon, Korea), and The University of Adelaide (Australia).

14 http://www.iot2008.org/

15 http://www.iot2010.org/

16 Ken Sakamura is a Japanese Professor in information science at the University of Tokyo, Japan. He is the "father" of TRON, the real-time operating system architecture which is a dominant and essential part of most embedded systems in Japan today. He is also Director of the YRP Ubiquitous Networking Laboratory (UNL) and the Chair of Japan's T-Engine Forum and µID Centre. See http://www.tronshow.org/index-e.html

In China, research in the field of Internet of Things is viewed as essential to foster economic growth and catch up with the developed countries. Since 2006, several research institutes have been involved in a far-reaching project, including Shanghai Institute of Microsystem and Information Technology (SIMIT), Chinese Academy of Sciences (CAS), Nanjing University of Aeronautics and Astronautics, Northwestern Polytechnical University of China, with strong support from Chinese government. Researchers in Electrical & Electronic Experiment Demonstration Centre of Nanjing University of Aeronautics and Astronautics have already developed a wireless sensor network platform of their own intellectual property, which includes ad hoc network wireless sensor node, data storage and data remote access terminal.

A promising initiative for pushing forward the limits of imagination, creativity and audacity with respect to the Internet of Things is "Council" – a loose group of professionals, animated by Rob van Kranenburg, Media theorist, which includes artists, designers, coders, thinkers and tinkerers. The members of this open consultancy/think-tank "*have been through the full range of emotions and conceptual breakdown that comes with grasping the territory, the full logistical, business, social and philosophical implications of the Internet of Things*."[17]

2.2. Industry perspective

The first industrial realisation of the Internet of Things, in the sense of RFID tags embedded in objects, was actually the Presto network in 1998[18]. Despite this forerunning initiative, during ten years, the Internet of Things was more a topic for research, especially in the Auto-ID Labs, than for industry.

When in January 2005 Wal-Mart and the U.S. Department of Defence demanded that their major contractors and suppliers mark their shipments with RFID tags for inventory control, Kevin Ashton said: "*It is an incredible milestone in the development of the technology. We need to understand that January 2005 is more the end of the beginning than anything else. When RFID really gets to go to the ball. It has kind of been a Cinderella technology in the basement of the computer revolution for the last ten years.*" The explosion of the RFID market in 2005 marked the dawn of the thinking about the Internet of Things…

Then, in 2008, an open group of companies launched the IPSO Alliance to promote the use of Internet Protocol (IP) in networks of "smart objects"[19]. The IPSO alliance now boasts 53 member companies, including Bosch, Cisco, Ericsson, Intel, SAP, Sun Microsystems, Texas Instruments, and – since December 2009 – Google and Fujitsu. Several large companies have

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17 http://www.theinternetofthings.eu/

18 Henry Holtzman, now Chief Knowledge Officer of the MIT Media Lab, did a project back in 1997 involving RFID tags put onto Pokemon figures. Along with MIT Lab's professors Andrew Lippman and Michael Hawley, Holtzman created in 1998 a commercial company, Presto Technologies, to output Internet of Things products. See Wired article of February 2000 at http://www.wired.com/wired/archive/8.02/mustread.html?pg=14

19 Smart objects are defined by the IPSO Alliance as being small computers with a sensor or actuator and a communication device, embedded in objects such as thermometers, car engines, light switches, and industry machinery. They enable a wide range of applications in areas like home automation, building automation, factory monitoring, smart cities, health management systems, smart grid and energy management, and transportation.

already invested in Internet of Things applications such as, among others, ATOS Origin, AT&T, Cisco, Deutsche Telekom, Ericsson, Fujitsu, Google, Hitachi, IBM, Intel, Motorola, Oracle, Qualcomm, SAP, Siemens, Telefonica, Texas Instruments, Thales, VeriSign and Verizon.

Furthermore, as the Internet is running out of addresses, in the near future it will be moving to a new protocol, IPv6. The current system, IPv4, has roughly four billion addresses. The new address space can support 21^{28} (about 3.4×10^{38}) addresses, which means, to take a commonly used analogy, that it provides enough addresses for every grain of sand on every beach in the world! While it is unlikely that we will be assigning IP addresses to grains of sand, the idea of assigning them to each of the more or less 5,000 daily objects that surround us, is quite appealing. With the right technology in each object (e.g., an RFID tag) and the right network in the surroundings, it will become easy to locate and catalogue items in a few seconds and to reap the benefits of the vast array of new information that communications among them will provide. IPv6 is undoubtedly one of the steps to making the Internet of Things a reality. The IPv6 Forum[20], which is based in Europe, is working towards deploying IPv6 in line with the European Commission Communication of 27 May 2008[21].

In Europe, SAP has been an early promoter of the Internet of Things along with the Internet of Services. Noting that the Internet of Things combines the power of ubiquitous networking connectivity with modern sensor technologies, SAP highlighted the merging of the digital world with the physical world (i.e. information concerning the identity, location and condition of physical objects can be made available through the Internet anytime and anywhere), the capability of objects to communicate with each other and hence become active participants in global business processes, thus leading to tremendous efficiency gains in many industries.

But over the last few years, beyond sporadic announcements and initiatives from industry, the Internet of Things has been ramping up[22]. Some specific Internet of Things products have indeed gained visibility; few examples are given below:

- Violet's Nabaztag[23] (2005), a cute bunny that can deliver anything from ambient information through lights and sounds to verbal information,
- ZeroG Wireless (2006), a new paradigm of wireless connectivity through low-cost, small-size Wi-Fi chips embedded into any system including consumer electronics, smart energy devices, home and building controls, portable medical sensors, and

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20 http://www.ipv6forum.com/index.php

21 COM(2008) 313 final.

22 Top 10 Internet of Things Products of 2009 http://www.readwriteweb.com/archives/top_10_internet_of_things_products_of_2009.php

23 Nabaztag, a multipurpose, Internet-connected mini-robot that talks, hears, smells objects, blinks and moves, was invented by Rafi Haladjian and Olivier Mével, and manufactured by their company, named Violet. On October 20, 2009, following a long period of technical difficulties, ultimately leading to Violet's bankruptcy, Mindscape purchased Violet.

sensor networks), and T2TIT (a software solution that enables secure and privacy-friendly communication between objects,

- Arduino (2008), an open-source electronics prototyping platform intended for artists, designers, hobbyists, and any "tinkerer" interested in creating interactive objects or environments,
- Alcatel-Lucent's Touchatag (2008), a contactless application service for consumers, application developers and businesses, which by using Radio Frequency Identification (RFID), Near Field Communication (NFC) and 2D barcode technology provides users with one-touch, fast and easy access to, among other things, information, registration, ticketing and payment,
- Arrayent's Internet-Connect System (2009), a turnkey communication system that enables companies to connect their products to smartphones and computers via the Internet,
- Usman Haque's Pachube (2009), a service that lets the user tag and share real-time sensor data from objects, devices, buildings and environments around the world,
- Haier's Internet of Things refrigerator[24] (2010), the world's first refrigerator that can store food but also be connected to a network, for food management, and be connected with the supermarket for enhancing consumer experience.

What these first Internet of Things applications point out to is a "metamorphosis of objects" from *artefacts* (objects that are simple, hand manufactured one by one at local scale, and activated by muscular energy) to *machines* (objects that are complex, gauged, composed of several parts, and whose electric power source is neither human nor animal) to *products* (objects that are mass manufactured) and finally to *gizmos* (objects that are unstable, modifiable by the user, programmable, and short-lived)[25].

The emergence of the Internet of Things is likely to provoke industry disruptions and transformations as the latter often originate from major technological breakthroughs. However, what we observe at this early stage of Internet of Things deployment is that established industry incumbents and new entrants co-exist in the embryonic marketplace. Focusing on competence enhancement, the former do not seem to have great difficulty crossing the chasm created by the Internet of Things disruption (e.g., Cisco's *Intelligent Urbanization Initiative*, IBM's *Smart Planet*) while new entrants, favouring competence destroying innovations, rise rapidly to visibility and significant presence on the market by holding market niches (e.g., Arduino, Arrayent, Pachube, Violet from 2003 until 2009). This shows that changes in the emerging Internet of Things industry are likely to come more from the introduction of new business models (i.e. the organising principles and templates around which a business is built) than from the seniority and size features of the companies.

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24 Haier is a Chinese company founded in 1984 (adopted current name in 1992), headquartered in Qingdao. It is the world's top refrigerator producer.

25 Source: from Bruce Sterling, *Shaping Things*, 2005.

2.3. *Government perspective*

Several countries have recognised the importance of the Internet of Things for future economic growth and sustainability. From 2006 onwards the European Commission launched public consultations and stimulated widely open discussions on RFID and the Internet of Things, especially regarding critical policy issues such as governance, privacy, and resilience/security. These initiatives reached their climax in 2008 when the French Presidency of the European Union organised a Ministerial Meeting in Nice to address the Internet of Things within the broader context of the Future Internet. During the same period, the U.S. Government commissioned a series of studies that emphasized the strategic importance of Internet of Things for U.S. relative wealth and economic power. In 2009, Chinese Premier Wen Jiabao himself announced China's intention to push national industry to make a breakthrough in wireless sensor networking, seen as a key technology in the Internet of Things[26].

At the Final Conference of the EU-funded CASAGRAS1 coordination and support action[27], which took place in London on 6-7 October 2009, the project leaders noted that their work had proved without doubt that

"There is the need and will for international co-operation. China, Japan, Korea and the USA are on board. Europe has taken the lead and now needs to drive the initiative as a truly global partnership. It has also been shown that governments, industry and business lacked awareness of the Internet of Things and of what it offered. Awareness and education programmes are key requirements in creating a better understanding of the potential and benefits, and these programmes should be especially directed at the SME community."

2.3.1. The European Union

The concept of Internet of Things was adopted by the European Union in the Commission Communication on RFID, published in March 2007[28]. But it had been beforehand debated at a workshop organised in Brussels by the European Commission's Information Society and Media Directorate-General (DG INFSO) on 6 and 7 March 2006[29].

The Council conclusions of November 2008 on Future Networks and the Internet:

- recognised that "*that the Internet of Things is poised to develop and to give rise to important possibilities for developing new services but that it also represents risks in terms of the protection of individual privacy*",

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[26] When Chinese Premier Wen Jiabao heralded the Internet of Things as a national imperative for China, it received surprisingly little play in the western world, but in Asia it was widely advertised since it was acknowledged as an important moment signalling that not only government leaders there realise that wireless sensor networks are critical to China's future as a manufacturing power, but the Internet of Things will pervade many other industries where China is, or hopes to become, a global leader.

[27] CASAGRAS was coordinated by AIM UK and included the following non-European partners: YRP Ubiquitous Networking Laboratory (Japan), Supply Chain Innovation Centre (Hong Kong), Electronics and Telecommunication Institute (Korea), and Q.E.D. Systems (USA).

[28] COM(2007) 96 final of 15 March 2007.

[29] ftp://ftp.cordis.europa.eu/pub/ist/docs/ka4/au_conf670306_buckley_en.pdf

- welcomed the Commission’s intention to "*adopt a communication in 2009 on the Internet of Things, presenting architecture and governance issues and identifying a series of concrete actions to initiate*", and
- invited Member States and the Commission to "*deepen, with respect to the Internet of Things, the reflection on the development of decentralised architectures and promoting a shared and decentralised network governance*" and "*contribute to ensuring the confidentiality, security, privacy and ethical management of the data that will be exchanged on the Internet of Things, for example by promoting where appropriate the possibility of deactivating RFID chips or any other way which provides empowerment and user control.*"

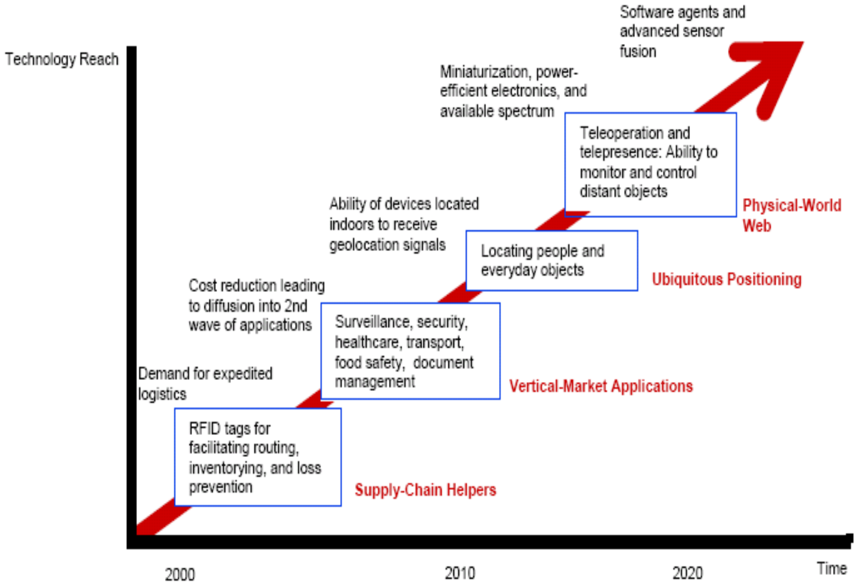
2.3.2. The United States

In April 2008, the U.S. National Intelligence Council published a report on "Disruptive Civil Technologies – Six Technologies with Potential Impacts on U.S. Interests out to 2025". These technologies are: Biogerontechnology; Energy Storage Materials; Biofuels and Bio-Based Chemicals; Clean Coal Technologies; Service Robotics; *The Internet of Things*.

The NIC report was prepared by SRI Consulting Business Intelligence[30]. As regards the Internet of Things, it stressed that

"By 2025 Internet nodes may reside in everyday things – food packages, furniture, paper documents, and more. Today's developments point to future opportunities and risks that will arise when people can remotely control, locate, and monitor even the most mundane devices and articles. Popular demand combined with technology advances could drive widespread diffusion of an Internet of Things (IoT) that could, like the present Internet, contribute invaluably to economic development and military capability."

30 Appendix on Internet of Things can be consulted at http://www.dni.gov/nic/PDF_GIF_confreports/disruptivetech/appendix_F.pdf



Source: SRI Consulting Business Intelligence

According to SRI Consulting Business Intelligence, the technologies of the Internet of Things are the following:

Enabling Building Blocks *These technologies directly contribute to the development of the IoT*	**Synergistic Technologies** *These technologies may add value to the IoT*
Machine-to-machine interfaces and protocols of electronic communication	Geo-tagging/geo-caching
Microcontrollers	Biometrics
Wireless communication	Machine vision
RFID technology	Robotics
Energy harvesting technologies	Augmented reality
Sensors	Mirror worlds
Actuators	Telepresence and adjustable autonomy
Location technology	Life recorders and personal black boxes
Software	Tangible user interfaces
	Clean technologies

A few months later was published the fourth instalment in the National Intelligence Council-led effort to identify key drivers and developments deemed likely to shape world events a decade or more in the future[31]. This report highlighted once again the importance of the Internet of Things, also named Ubiquitous Computing, i.e. the widespread tagging and networking of mundane objects such as food packages, furniture, room sensors, and paper documents:

"Such items will be located and identified, monitored, and remotely controlled through enabling technologies – including RFID, sensor networks, tiny embedded servers, and energy

31 National Intelligence Council, "Global Trends: A Transformed World", NIC 2008-003, November 2008.

harvesters – connected via the next-generation Internet using abundant, low cost and high-power computing (...) These technologies could radically accelerate a range of enhanced efficiencies, leading to integration of closed societies into the information age and security monitoring of almost all places. Supply chains would be streamlined with savings in costs and efficiencies that would reduce dependence upon human labour."

The U.S. Department of Defense (DoD), which operates the largest and most complex supply chain in the world, awarded in January 2009 a contract for 429 million dollars in DASH7 infrastructure. This represents a major development in terms of global adoption of an ultra low-power wireless sensor networking technology based on a single global standard.

2.3.3. China

In the second half of 2009, a number of significant public speeches were delivered about Internet of Things in China. On 7 August, Chinese Premier Wen Jiabao made a speech in the city of Wuxi calling for the rapid development of Internet of Things technologies. On that occasion, he provided the following interesting equation: *Internet + Internet of Things = Wisdom of the Earth*. This equation suggests that the Internet and the Internet of Things can be used to help humans understand the consequences of individual actions, and the relationship between those actions and physical laws ("wisdom of the Earth"). For example, we can choose to let a million vehicles idle on the highway, but in doing so we cannot escape the social consequences in terms of the environment and health.

互联网+物联网=智慧地球

Wen Jiabo followed up with another speech on 3 November at the Great Hall of the People in Beijing, in which he called for breakthroughs in wireless sensor networks and the Internet of Things.

It is expected that in 2010 China will push forward with major policy initiatives to speed up the development of its national industry. At the same time, Chinese provinces, municipalities and industrial parks will release supporting policies. In December 2009, Zhou Hongren, executive vice chairman of the Advisory Committee for State Informatization (ACSI), advised that Guangdong Province use the Internet Protocol version 6 (IPv6) first around China, because the IPv4 resources will be used up by 2012, which will somehow block the growth of the Internet of things in China[32].

2.3.4. Japan

Japan's involvement in the general field of ICT has been spelled out in the New IT Reform Strategy (January 2006) and Priority Program 2008 (August 2008) at the Strategic

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32 By September 2008, there had been 66,290 allocated IPv6 addresses worldwide, including 14,729 for the U.S., followed by Germany, Japan, France, Australia, and South Korea. While Brazil had then 128 IPv6 addresses, the figure was only 54 in China, which is insufficient to meet the demand of advanced applications and restrains the steady and sustainable growth of the Internet industry.

Headquarters for the Promotion of an Advanced Information and Telecommunications Network Society (IT Strategic Headquarters). The goal is *"to realise ubiquitous and universal network society where everyone can enjoy the benefits of IT."*

The Ministry of Internal Affairs and Communications (MIC) promotes R&D and standardisation of ICT for enhancing Japan's international competitiveness. The Ministry of Education, Culture, Sports, Science and Technology (MEXT) promotes research in important fields such as life science, information technology, nanotechnology and materials, and the utilisation of quantum beam. In the field of ICT, one of the main goals is a safe ubiquitous network society, such as next-generation electronic tags. In January 2010, MEXT has released a White Paper on Science and Technology 2009.[33] The Ministry of Economy, Trade and Industry (METI) started in 2008 the Green IT Project aiming at a balance between environment and economy.

In February 2009, Japan's METI and European Commission's DG INFSO concluded a Memorandum of Cooperation on RFID, wireless sensor networks and the Internet of Things. Besides a joint commitment to developing a regular dialogue, the two entities will cooperate on social acceptance (accessibility, consumer convenience, privacy, etc), networked RFID and future Internet of Things, health and environmental impact, and harmonisation issues (code system, definition of messages, development of open global standards and/or harmonisation of regional standards, interoperability between different systems).

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[33] http://www.mext.go.jp/english/wp/1288376.htm

Below are given the main R&D priorities for MIC, MEXT and METI.

	MIC	MEXT	METI
Networking	All-packet type, highly functional network; increase in Internet traffic; information-communication infrastructure; all-optical networks with ultra-high speed and extremely low power consumption; sharing of multiple wireless systems with the same frequency; wireless systems in unused frequency bands; beyond the next-generation network.		
Ubiquitous networking	RFID tags and sensors (2004-2007); Ubiquitous Platform Technology R&D (since 2008); digitalisation of home appliances; broadband networks.		
Device/display		Innovative spin device; large-capacity, high-speed storage to realise high-function and ultra low-power consumption computing.	Miniaturisation technologies for a 45-nanometer or smaller technology node; next-generation memory with a non-volatile function; chip technology to reduce power consumption in information household appliances; 3D integration technology in a semiconductor device (since 2008); Green IT (router to control power consumption, etc).
Security and software	Prevention of information leaks; technologies for detecting, mitigating and preventing BGP prefix hijacking.	Visualisation techniques for software construction status; software for system integration and cooperation to realise e-Science.	Bot trapping/analysing system; prevention of damage caused by new types of threats to information security; management techniques for developing a secure IT environment for people; voice recognition for consumer convenience.
Human interface and content	Super-ultra-high-density image broadcasting; future 3D imaging techniques; network voice translation (one of the Pioneering Projects for Accelerating Social Return); believability of information among various types of information available on networks.	Super-high-performance database platform software enabling the management and utilisation of huge amounts of data; software enabling the seamless use of various computers distributed throughout Japan.	Accurate search and analysis of required information from among large amounts of data and infrastructure for futuristic business (Information Grand Voyage Project).
Robotics	Robots with versatile sensors and devices that can provide services like life support and welfare/caretaking support.		Industrial robots, service robots, and special environmental work robots; intelligence technologies for the rapidly changing environment of production and the living environment; standardised methods to connect and control various components of robots and to make reusable parts (modules).

Source: from the White Paper on Science and Technology 2009

2.4. Smart City perspective

The initiatives of IBM (*Smarter Planet*: "instrument the world's systems, interconnect them, make them intelligent") and Cisco (*Intelligent Urbanization*: "using the network as a utility for integrated city management"), already mentioned, but also General Electric (*Ecomagination*: "solve today's environmental challenges and benefit customers and society at large") and other multinational companies, are typical examples of the contribution of the Internet of Things to the development of Smart Cities.

By 2050, 70% of people on Earth will live in cities, which suggests that more than states, regions or perhaps even nations, cities are increasingly for businesses the central measure for success or failure. New Songdo City in Korea is still today the most famous smart city project so far, covering all aspects from infrastructure to architecture, transportation, utilities, density, open space and parks, in short everything that defines the substance of an urban area. There has been also the Ubiquitous Network Project of Tokyo University Professor Ken Sakamura, which started in 2007 with a field test in Tokyo's Ginza shopping district where more than 1,200 chips, 270 infrared spotlights, and 16 Wi-Fi stations were placed on lampposts, flower beds, stores, and underground subway tunnels.

Many other smart city projects have emerged over the last few years in different parts of the world. They concern the rise of "new cities" – e.g., King Abdullah Economic City (KAEC) in Saudi Arabia, (MASDAR) in Abu Dhabi, Gujarat International Finance Tec-City (GIFT) in India, the Infocomm Development Authority (iDA) of Singapore – or the modernization of existing cities – e.g., Amsterdam CITYNET in The Netherlands, Borlänge City in Sweden, San Francisco TechConnect in California, U.S., Yangzhou in China's Jiangsu province, Santander in Spain. Using Internet of Things technology that offers wireless communication and real-time data such as temperature, pressure, vibrations, and energy measurements between the devices which surround us, endless applications are being developed aiming at positioning cities as attractive global investment nodes for advanced manufacturing and service industries.

The development of Smart Cities is often – not always – carried out through a partnership between the local public authorities and the private sector (e.g., Cisco-KAEC, GE-City of Yangzhou, IBM-Stockholm). The European Commission, building upon its 10-year old IADS experience[34], intends to support initiatives regarding Smart Cities through the "Future Internet Public Private Partnership" (FP7, 2011-2012 Work Programme) and the ICT Policy Support Programme (CIP, 2010 Work Programme).

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34 In 1997, under the 4th Research Framework Programme (FP4), the European Commission selected 12 Integrated Applications for Digital Sites (IADS) projects founded on strong private-public sector partnerships and funded primarily by industry and research bodies. 52 million euro of EU funds were then attributed to the 12 projects, i.e. an average EU contribution of 4.4 million euro and a total cost per project amounting to an average of 11 million euro. Participants in these IADS projects included 43 digital cities and towns and 21 digital regions.

3. IoT research and technological development in Europe

The debate about Internet of Things in Europe rose at a time when the structure of the 7th Research Framework Programme (FP7) was already established. It is obvious that the holistic approach adopted by the "Networked Enterprise and Radio Frequency Identification (RFID)" unit (DG INFSO/D4) in its initiatives, especially the Communication of June 2009 and its follow-up, deemed to draw attention in policy makers, academics and industry and to yield considerable and lasting benefits for the European economy and society, does not fit well the FP7 structure with its few "Challenges" and associated "Objectives". During the implementation of the first two ICT-FP7 Work Programmes (2007-2008 and 2009-2010), the networking and communications aspects of IoT fell clearly within the remit of Challenge 1 (*Pervasive and Trustworthy Network and Service Infrastructures*) whereas the hardware aspects (nanotechnologies, sensor technologies, solutions bridging nano and micro systems, etc.) matched better the contents of Challenge 3 (*Components, Systems, Engineering*) and the applications aspects could be found relevant to the contents of Challenge 5 (*Towards sustainable and personalised healthcare*), Challenge 6 (I*CT for Mobility, Environmental Sustainability and Energy Efficiency*), and Challenge 7 (*ICT for Independent Living, Inclusion and Governance*).

This discrepancy between a vision (Internet of Things), the related technologies (RFID, sensors, wireless sensor networks, nanotechnologies, etc.), and the available policy instruments (FP7) will unfortunately not disappear rapidly. It would not be advisable indeed to modify the structure of FP7 for accommodating just one particular vision. But it can be regretted that the FP5 idea of "cross-programme actions" was abandoned in the next Research Framework Programmes, and hence the possibility of clustering the projects from different "Challenges" with respect to their adherence to the IoT vision should be explored. The recommendations put forward by a number of relevant industry groups, especially the IST Advisory Group (see 3.1 below), go in the same direction.

Meanwhile, in 2008, DG INFSO/D4 had taken the initiative of defining the contents of a specific call for proposals (Call 5 of the 2009-2010 Work Programme) for addressing Internet of Things in a dedicated and holistic way. The response to this call, which was received at the end of 2009, was high and the overall quality of the proposals very good or good.

3.1. Setting the scene

The IST Advisory Group (ISTAG)[35], which was set up in 1998 to advise the Commission on the overall strategy to be followed in carrying out the ICT thematic priority under the European Framework Programme for Research, stated in a 2009 report[36] that "*the development of a Future Internet with its three components (Internet of services, network architectures and technologies, Internet of things) [was] a key development for the ICT sector*". Referring to the Internet of things as "*an explosive increase in the number of devices*

35 From 1999 onwards, ISTAG popularized the phrase "Ambient Intelligence" – initially a technology vision for the timeframe 2010-2020 – that had been coined by Eli Zelkha and Brian Epstein, from Philips, in 1998.

36 ISTAG, "Revising Europe's ICT Strategy", February 2009.

attached to the Internet, including many machines, sensors and intelligent devices", this report recommended "*to support research and development in the area of self-organizing embedded systems and autonomic diagnosis to provide the infrastructure for new applications in the coming Internet-of-Things*".

According to ISTAG, technical research challenges to turn the vision of Internet of Things into reality have to be addressed at multiple layers[37]:

- Edge technologies, such as sensors and actuators, passive/active identification tags, embedded systems, which are attached to real-world objects and make them smart enough to participate in Internet of Things scenarios.
- Networking technologies, such as fixed, mobile wired and wireless networks allowing the highly available bidirectional communication on different levels (between real-world objects, applications and services offering functionality).
- Middleware systems putting real-world data into the context of various Internet applications.
- Platform services that run in the background to support a superior management of all involved technical components in an integrated way ensuring scalability, high availability, and safety/security.

In its 2009 report, ISTAG goes further, arguing that based on Europe's experience in several fields – Embedded Systems, Wireless Autonomous Transducer Systems, Robotics, Components, and Nano-Electronics/Systems – the Internet of Things could be linked to an Internet of Services provided that "technology for context-aware, reliable, embedded, energy efficient and secure distributed networks of cooperating sensors end actuators, as well as the energy provision for this technology" is made available. Such technology would require a 'total system" solution (from systems theory of massive distributed networks through embedded software platforms to the development of "more than Moore" nano-system design) as well as new models of interaction ("beyond the desktop metaphor").

3.2. Call 5 of the ICT theme in the 7th Research Framework Programme

Call 5 of the ICT theme managed by DG Information Society and Media under the 7th Research Framework Programme (FP7) was the first time the Internet of Things community was invited to submit proposals for collaborative research in the field. It was a test of the ability and willingness of Europe's ICT community to deal cooperatively with the Internet of Things challenges. The description of the work proposed in the Call text was the following:

Architectures and technologies for an Internet of Things

- Architectures and technologies using open protocols, which enable novel Internet-based applications including – but not restricted to – business/enterprise scenarios.

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[37] Source: ISTAG, Working Group on Future Internet Infrastructure, Version 8, 23 January 2008.

They should use information generated at the periphery of the network from the virtual and physical worlds with aggregation of those, and allow action on the physical world. Physical world event information are generated by tags, sensors, actuators and wireless devices. Related processes and applications may be object- or location-centric and cover management capabilities of various classes of events, such as real world events (sensor based), behavioural/people events, or business events. For business scenarios, traceability networks correlated with logistics and order or billing flows are of particular importance.

- Optimised technologies covering distribution of intelligence between the edge network and the more centralised business/process information system. This includes service discovery systems as well as scalable, secure, open middleware necessary to put real world data into the context of various Internet applications with event processing, separation and filtering. Of particular importance are the integration and interoperability with the mainstream business/process management platforms and tools and the necessary management of varying data ownership across the edge device/object life cycle.
- Architectural models enabling an open governance scheme of the Internet of Things, without centralised gatekeeper lock-in of critical business/process functionalities.

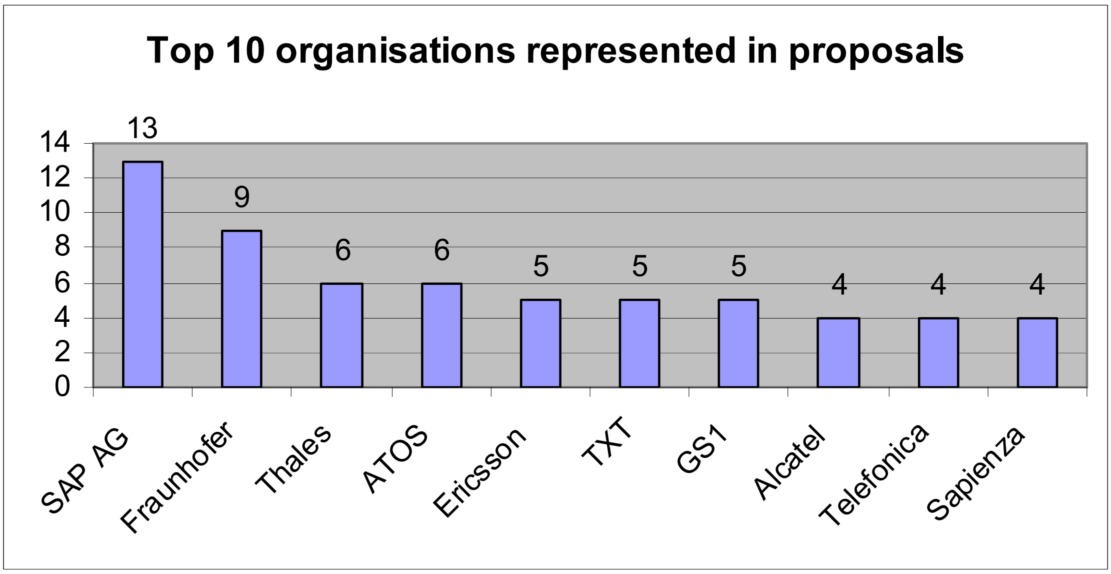
DG INFSO/D4 organised two information days in Brussels, respectively in February 2009 and September 2009, to raise awareness of the ICT community about the contents of the Objective 1.3 "Internet of Things and Enterprise Environments" and to facilitate consortium building among sector actors.

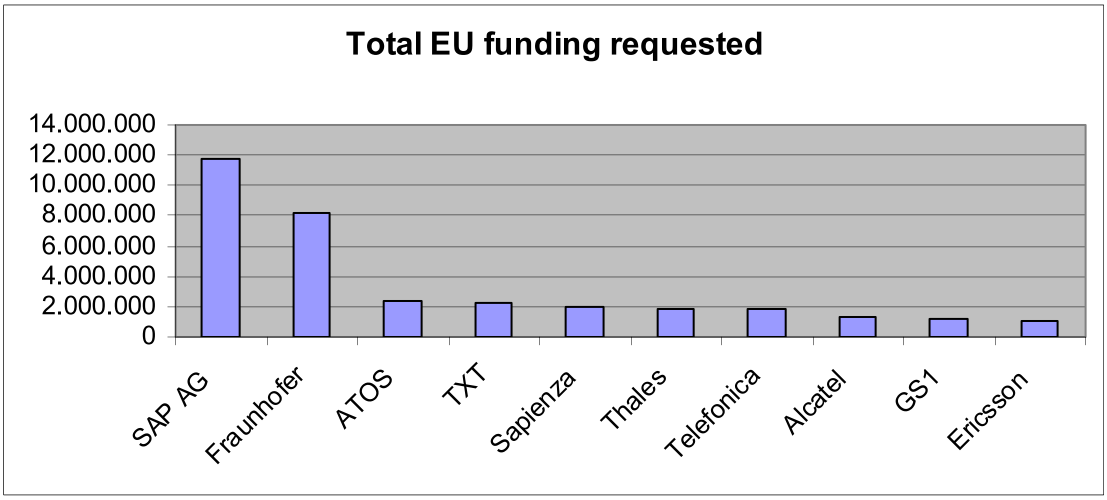
The call resulted in 45 R&D proposals related to the Internet of Things, including 9 Integrated Project proposals and 36 Specific Targeted Research Project proposals.

The call attracted 357 partners, including 178 (50%) from industry, 93 (26%) from academia, 69 (19%) from research organisations, and 17 (5%) from the public sector. This underlines the strong interest of industry in IoT research and the ability of all stakeholders to build balanced consortia. Interestingly, small- and medium-sized enterprises (i.e. roughly, independent companies with less than 250 employees) represent a significant 47% of all companies, which is a good indicator of the dynamism of the emerging IoT industry.

EU organisations represented 86% of all organisations involved in the call, the other 14% including countries like Norway, U.S., Brazil, Canada, Israel, and Japan. 53% of the total number of participating organisations came from only five EU countries, which shows a high degree of concentration. Germany had 49 organisations involved, followed by Spain (46), Italy (39), the United Kingdom (32) and France (23). Some countries surprisingly scored a relatively low participation figure (France, the Nordic EU countries…); conversely, countries like Greece, Switzerland, Ireland and Poland scored well in that respect.

The diagrams below give some indication of the leading organisations involved in IoT research in Europe.





4. Conclusion

The Internet of Things is a vision that encompasses and surmounts several technologies at the confluence of Nanotechnology, Biotechnology, Information Technology and Cognitive Sciences. Over the next 10 to 15 years, the Internet of Things is likely to develop fast and shape a newer "information society" and "knowledge economy", but the direction and pace with which developments will occur are difficult to forecast.

In fact, when considering the spectrum of possibilities for the Internet of Things in the 2020-2025 timeframe, little can be said at this stage since the technology is still being refined, the industry is in a process of reconfiguration, and the market is embryonic. The main uncertainties can be grouped around two axes: the timing of developments (slow versus fast) and the depth of penetration (niches versus ubiquity)[38].

In terms of timing, the Internet of Things will grow all the more rapidly if favourable policies, technological progress and business collaboration prevail. This is actually the sort of "Golden Triangle" which the European Commission is seeking to harness through its regulatory (Directives, Recommendations), research (7th Research Framework Programme) and innovation (ICT Policy Support Programme) instruments.

In terms of penetration, the Internet of Things could permeate the whole economy and society if the public concerns that generally impede technological change (in particular privacy and security) are addressed and warranted in such a way that trust and enthusiasm are reflected in strong market demand. Otherwise, should these demand signals not materialise, the Internet of Things would remain limited to a few niches (e.g., health care, logistics, manufacturing, health care, security, transportation).

Overall, much will depend, among other factors, on technological advances in miniaturisation and energy-efficient electronics, advances in software acting on behalf of people and actually fusing sensor information from heterogeneous sources, the size and nature of demand in the private sector (commerce, logistics, etc.) and the public sector (defence, health care, etc.), the effectiveness of initial waves of IoT in reducing costs/improving efficiencies, the ability of devices located indoors to receive geolocation signals, and the efficient use of spectrum.

The turn that the debate has taken in 2009 – a year which might be regarded later as the true beginning of the Internet of Things – with the U.S. and China joining Europe in addressing the challenges and opportunities of this vision, indicates that a growing number of analysts, not only in industry and academia but also among public decision makers, have become convinced that the Internet of Things will ignite fresh demand for a wide range of hardware and software to store, process and search the trillions of data from tags, sensors and other identification and location devices to actually create useful knowledge. *It does feel almost like the beginning of the Internet*[39]!

The journey to the Internet of Things will be a long one. Besides some well-known embryonic applications (Arduino, Nabaztag, Pachube, Touchatag, etc.), today objects can only exchange information within "intranets of things", i.e. environments within which processes are controlled. These objects cannot yet address any Internet of Things, which by definition should be open, uncertain and complex. One of the main challenges of the Internet of Things is therefore to transform connected objects into real actors of the Internet by developing and

[38] Source: U.S. National Intelligence Council – "Disruptive Civil Technologies: Six Technologies with Potential Impacts on U.S. Interests Out to 2025", pp39-42.

[39] Source: Katharine Frase, vice president for emerging technologies at IBM Research, quoted by The New York Times in "Smart Dust? Not Quite, but We're Getting There", 31 January 2010.

implementing appropriate applicative design methodologies[40]. This shift of paradigm involves major societal and ethical challenges that loom ahead and need to be tackled, certainly at European level but also at global level. The metamorphosis of objects, if left without any regulation or interference, might give rise to a genuine, extensive surveillance society. Each individual would spontaneously document his life by complementing factual information on his journeys, locations and transactions, which are today aggregated, with the micro-events of his day-to-day intimate life. Besides the technology, an open dialogue must take place on the ethics of the Internet of Things in order to mitigate the risks of a society which would be transparent for a few and opaque for all the others.

The Internet of Things fundamental challenges will be addressed in the next ICT-FP7 Work Programme (2011-2012) by inviting multi-stakeholder, multidisciplinary consortia to put forward ambitious proposals on the related technical aspects.

At the same time, DG INFSO will seek to organise and steer an open debate on the different "lines of action" described in the European Commission Communication on the Internet of Things.

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40 See Philippe Gautier, "Internet des Objets: Objets connectés, objets communicants… ou objets acteurs", http://www.refondation.org/blog/2385/internet-des-objets-objets-connectes-objets-communicants-ou-objets-acteurs