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The Internet of Things

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Abstract: *This paper traces the speed, scope, impact and shape of the challenges that are posed by what is now termed 'Internet of Things'. The scope of IoT is informed by the crisis of representation and the growing importance of the notion of 'data'. In the case of IoT the promise seems to be that it generates a new ratio between data and noise: it brings raw data to the enduser, it allows the enduser to generate new data and builds new correlational tools that find data where only noise was thought to be before, either because it could not be massively scaled, the sensors were not susceptible enough, or the data mining algorithms not suitably refined.*

IoT is comprised of a number of technological protocols that aim to make up to 'glue' of connecting things to other things and to databases, that are currently being shaped and discussed such as ipv6 for IP, and EPC global, OID, federated ONS for RFID. It is not sure what its relationship is to Future Internet, if it is the future Internet, or a layer of services and applications, or a set of communication protocols specifying how objects can be enhanced to become smart objects. In its current phase it appears to be all. The speed with which the paradigm of connecting communicating objects has taken over the full range of connectivity protocol (ipv6), hardware (from cheap sensors to smart phones, ipads, tablets that are full blown computers), software (either proprietary in the cloud or collaborative open source), applications (ranging from location based services that link up to social networks to your car linked up to a particular brand network) and services (from carsharing with rfid cards (Buzzcar), to blinds texting you or your service layer that they are out of battery power (Designer) is determined by the collaborative power of the internet.

In this paper we outline its recent history, technological challenges and policy ecology. We end by sketching a possible framework for grasping its impact on the four layers it is comprised of: the value chain where all objects can be tracked, logged and traced, the service layer that will be build on this, the

smart city layer and its ultimate limit and scope of the Sensing Planet notion that aims to capture natural processes by globally distributed sensor grids to have counterpart in the cloud. We sketch the two basic policy and industry r&d approaches: a reactive approach that argues IoT is manageable and non disruptive, and a proactive approach that assumes the inevitability of a full IoT situation of 'total' connectivity and works back from this to identify the key moments of agency in policy tools and commercial products. Some assistance, we believe, can be gained by consulting a new and growing field of social research. Infrastructure Studies, a cross-disciplinary research area includes researchers from Information, Sociology, Political Science, and Computer Science. Together these researcher's goal is to develop case studies on infrastructure as well as novel methods for unpacking its importance for social life.

Introduction

“For the economy, the Internet of Things will bring a disruption - only companies that are able to exploit this new potential will survive. For the society, it will impose a new “social contract”, not only among humans but also among people and objects. The current policy challenges - notably security and privacy - will not wear off, far from it, but will require radically new approaches summoning up both technology and regulation. And new challenges will surely emerge, in particular ethics - what is the place of humans in a ‘new society’ where ‘thinking objects’ dominate and gradually conquer their autonomy?”

- Gerald Santucci Head of Unit “Enterprise Networking and RFID” at European Commission

It is rare that one is in the presence of an ontological shift. It is even more rare that one is in a position to shape it. Yet this is exactly the position many engineers, policy makers, and citizens are in today. In his seminal text, 'The Computer for the 21st Century' (Weiser, 1991) Mark Weiser was the first to voice the idea that miniaturization and ubiquity of sensors would eventually lead to the disappearing of computational elements 'into the fabric of everyday life' and the potential for computing as procedure, as visible hardware and as protocol, to move into an invisible background. Interestingly Mark Weiser himself - who passed away in 1999 - did not consider what he called 'ubiquitous computing' as something that would radically alter or change the relationship between humans and the new digitally hybrid environment. However, he did propose a series of ubiquitous computing scenarios which continue to involve both the rhetoric and the reality of computing today (Bell and Dourish, 2007)

From the 80s onwards there were different terms proposed: ambient intelligence, calm computing, ubicomp, pervasive computing, most of them pushed by industrial players such as Philips and IBM. Two dominant characteristics unite these different perspectives; first, a sense that internet connectivity is becoming increasingly ubiquitous and pervasive, and second, the idea that eventually everything – including mundane physical artifacts – will be connected.

In a 2007 conference appearance, the founding executive editor of Wired Magazine Kevin Kelly gave a lecture about the first 5000 days of the world wide

web. "In 5000 days," he argued, "less time than it takes for a child to progress through the school system, the world had been transformed." Kelly noted how online social networking through applications like Myspace and Facebook was changing the nature of social interactions. He referenced the different engagements with travel and with space made possible by searchable maps and direction services. And he emphasized the changing nature of expertise highlighted by free encyclopedias such as wikipedia. Kelly then moved on to discuss the next 5000 days of the web, here arguing that the speed in which the web has caught on and the haste in which it has transformed the industrialised world, showed no signs of slowing. "Everything," Kelly stated, "will be part of the web. Every item, every artefact ... will have some sliver of connectivity that will be part of the web." In other words, according to Kelly in 2007, before 2024, everything will be connected to the point where "the environment will become the web".

What Kelly was describing was no less than an "internet of things", namely, a world where a pair of sneakers becomes seen as "as a chip with heels: a car as a chip with wheels". Like the promise of air travel or space flight, this vision has been an idea long before it has been made a reality. And like other computing paradigms before it, this vision guides the direction of technical developments as much as it predicts them. (Bell and Dourish, 2007).

At the heart of the internet of things is a metaphor. Put most simply: it is a network of connected objects. Vehicles, machine components, domestic consumable durables, the clothes on your back, all are being hooked up to a network with a speed most of us have yet to comprehend. True, this internet of things is difficult to conceive. But then again, 5000 days ago, what newspaperman considered that the computer in the corner could shake the power of the printing press? What record company exec pondered the company's demise the first time they went online? What bibliophile imagined you could carry an entire library around in their briefcase? That such statement are more than mere rhetoric is evidenced by the increasing low cost of such technologies as Radio Frequency ID's that can be used to uniquely identify and track almost any physical artifact. As Neil Gershenfield noted as early as 1999, individual RFID tags have dropped below a one cent cost, making their adoption within diverse business areas not just technically possible but economically feasible as well.

Since that time, RFID and other technologies that are essential to an internet of things have been adopted in a variety of contexts. RFID tags are increasingly used in the pharmaceutical industry, as part of agriculture's value chain, and to combat cattle rustling, in addition to uses in a wide variety of contexts and business areas. Bit by bit, byte by byte, this internet of things is being assembled, much without a wider public's knowledge of the idea, much less their input or consent. The discourses around these developments are in a variety of places and in different languages and styles. The people that shape the discussion come from very diverse backgrounds: Kevin Kelly started to work as a writer and photojournalist. Bruce Sterling writes science fiction novels. Usman Haque is an architect and designer, founder of Pachube. Rob van Kranenburg studied Language and Literature and is a writer. Rafi Haladjian is the founder of the first Internet Company in France in 1994, and Violet, including the Nabaztag Rabbit, one of the first 'smart objects'. Adam Greenfield is a designer and writer who recently founded urbanscale.org Mike Kuniavsky is a user experience design, process and strategy consultant and the author of two books on user experience design and research. Actually, there is not one engineer or technologist among the first 10 of the Postcapes list 100 people "influencing the topic on a daily basis whether through their evangelizing, standardizing or through their own companies." The other three influencers listed are *Design Consultancy Berg* by Matt Webb, Jack Schulze Matt Jones, and Timo Arnall as Creative Director. *The Web of Things*, a "community of developers, researchers, and designers that explore the future of the physical Web" operated by Vlad Trifa and Dominique Guinard, and *Council*, a *thinktank for the Internet of Things*.

In *Opportunities, Challenges for Internet of Things Technologies* José Roberto de Almeida Amazonas have searched the IEEE Xplore® search engine (on December 2 2010) for "Internet of Things" restricting the year of publication to 2010. The search resulted in "150 papers, including conference proceedings and periodicals". China leads with an overwhelming 51.3% followed by Europe with 37.3%. The authors state that this does however not mean "a leadership in any of the following criteria: quality, originality, technical and/or scientific contribution, worldly knowledge dissemination." (2010:1) The number of American papers is distorted "because IoT-related research and development has been conducted under different names such as pervasive and ubiquitous computing, wireless sensor networks and so forth." (idem) The authors also see a difference of

approach: "Most American papers put the technology itself as the main objective while European papers focus on the use of the technology, i.e., they are more user-centric and care about the benefits IoT can provide to the society." (2010: 3)

Therefore, while many technical challenges remain to be overcome, the main themes and discourse around the internet of things are primarily social in scope and intent. This may be one reason why so many of the discourses and stories on this topic are deemed fuzzy: there is a clear gap between the writers and the engineers. This paper tries to bring these discussions and developments one step closer through analyses and commentary that link technical knowledge and expertise as well as work on internet of things policy and political importance.¹

1

Sean Dodson wrote the Introduction. Erin Anzelmo and Rob van Kranenburg are responsible for the first section: approaching the internet of things. Alex Bassi is the author of section 2 on the current technical challenges. Dan Caprio wrote the section on Policy, section 3. Section 4 on scope and impact is by Matt Ratto and Rob van Kranenburg. Erin Anzelmo provided building blocks for this section. Sean Dodson and Matt Ratto both did excellent editing on this position paper. Christian Katzenbach provided critical and productive feedback throughout the process.

1. Approaching the Internet of Things

Defining the Internet of Things

“When objects can both sense the environment and communicate, they become tools for understanding complexity and responding to it swiftly. What’s revolutionary in all this is that these physical information systems are now beginning to be deployed, and some of them even work largely without human intervention” (McKinsey & Company 2010)

As noted by most commentators and articles on the subject (Uckelmann, Harrison, Michahelles, 2011), the definition of internet of things is still rather fuzzy and subject to philosophical debate. Practically any book or report written on IoT starts with a discussion on previous definitions (Casagras, 2009), and each author seems to insist on adding their own special ingredient to the final recipe. This process is somewhat strange, from a technologist perspective, it is doubtful that Vint Cerf and Bob Kahn spent long hours in forging a definition for the internet - first came the technology, then the definition. There are many linguistic versions of the concepts comprising the internet of things technologies. Often the variations are a result of the blurring of products and technologies involved. Such terms vary from ambient technology, ubiquitous technology, sensor web, sensor network, wireless sensor networks, smart dust, smart cities, smart data, smart grid, cloud data, Web 3.0, and Object Naming System (ONS), to name but a few.

Variations also result from geographic or the national boundaries; for example, in China and Europe the term internet of things is widely accepted. While in the US, it is more commonly referred to as smart object, smart grid, data grid, cloud computing. Brian Cute, CEO of the Public Interest Registry suggested that a common agreement on terminology and concepts is necessary and “a sound understanding of the internet itself by all stakeholders cannot be assumed” (Cute, 2011). Whether we will get close to agree upon terminology largely depends on the applications that the technologies can enable. For the moment, we must agree to multiplicity.

The term "IoT" was initially used by Kevin Ashton in 1999, and became of widespread use thanks to the work of the Auto-ID Centre, a research group working in

the field of networked radio-frequency identification (RFID) and other emerging sensing technologies. However, the definition was not given at that time, and although there's a general agreement that IoT involves objects and connectivity, the precise wording is still to be found.

It is important to ensure a common understanding of what the term IoT encompasses and how it is used. While the information gathered by these new systems may be communicated via the internet, this does not necessarily mean that the internet as such will change or that there will be a new "form" of internet only intended to be used for information exchange between these new communication tools. For instance, Cisco foresees the IoT and the number of devices connected to the Internet exceeding the number of people populating the entire planet². And that's not just smart phones and tablets. Its sensors enabling a smart grid, smarter transportation flows, tracking the health of cattle, and medical devices monitoring the health of cardiac patients.

Rather than always interacting with humans, sensors will be interacting with each other automatically, updating our daily schedules. Devices will, for the most part, be mitigated through local area networks. It's true that devices will have a unique IP address in an IPv6 world. However, the business case does not yet support independent communication of every tagged item. Although there are self-evident societal benefits to individuals from this computing continuum, these "smart/connected" devices present privacy and security challenges, as well as opportunities, which require an examination of how traditional privacy norms like the US Federal Trade Commission Fair Information Practice Principles (FIPPs)³ should be applied to the IoT.

ENISA in their IoT/RFID Scenario Risk Assessment stated: "While there is no unique definition for the Internet of Things, a commonly accepted one is the ITU-T definition from 2005, saying that development of item identifications, sensor technologies and the ability to interact with the environment will create an Internet of Things." (ENISA, 2010) ITU Internet Report 2005 goes on to say: "the 2000s, we are heading into a new era of ubiquity, where the "users" of the Internet

² See <http://blogs.cisco.com/news/the-internet-of-things-infographic>

³ See <http://www.ftc.gov/reports/privacy3.fairinfo.shtm>

will be counted in billions and where humans may become the minority as generators and receivers of traffic. Instead, most of the traffic will flow between devices and all kinds of “things”, thereby a much wider and more complex Internet of Things. (ITU Internet Report 2005)

Within the EU research domain, the Cluster of European Research Projects on internet of things (CERP-IoT, now IERC) defines IoT as a " dynamic global network infrastructure with self configuring capabilities based on standard and interoperable communication protocols where physical and virtual “things” have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network” (Vermesan, 2009).

The EU project Casagras developed a more complex definition, expending quite an impressive effort in the process, as well as comparing its own definition with the existing ones. Its definition is as follows: “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 the development of independent cooperative services and applications. These will be characterised by a high degree of autonomous data capture, event transfer, network connectivity and interoperability” (Casagras, 2009).

The European Technological Platform EPoSS, in their 2008 report "Beyond RFID - The internet of things”, used a much leaner definition, and concentrated on the two aspects of IoT: the internet and “smart objects”. In this case, the definition used was: “a world-wide network of uniquely addressable interconnected objects, based on standard communication protocols” (Eposs, 2008).

Trying to simplifying the matter, and including all possible devices that belongs to the IoT domain, it is possible to consider the internet of things as the superset of all objects that are uniquely identifiable by electro-magnetic means and for which it is possible to specify a semantic and/or behaviour.

Not only is there disagreement on the nomenclature of the IoT, there is also disagreement on the scope of the IoT. Besides “things”, there is an emerging question if human users included in the definition, as hypothesized by the European Research Cluster on the IoT (IERC). A pan-European consumer group

wishes that the IoT be called “the internet of people”, so as to emphasize the human element (BEUC/ANEC, 2008) or the “Internet of Everyone” in a recent report published in 2011 funded by Accenture. While the IETF states that “Internet of things” concept refers to the usage of standard Internet protocols to allow for human-to-thing or thing-to-thing communication”, hence, including the human element in the very definition (Garcia-Morchon, 2011).

Phases of the Internet of Things

1.1 First Phase

The *first phase* encompasses the period of 1990 to 2005 and can be traced to the moment Mark Weiser chief scientist at Xerox Parc, publishes “The Computer for the 21st Century” in 1991 (Weiser, 1991) From the 1950s onwards the critical energy was spent on getting computers smaller, building a technological grid to host these and creating a psychological and social frame for bringing work to the home and private sphere.

Weiser realized that the dashboards for these models – the visualisations and experiential situations – were never meant for individuals, but instead for systems and large companies, institutions and think tanks. Weiser is the first to raise the problematic issue of the interface in everyday life and interactions. He began to wonder how best to access this virtual world not only through the keyboard and mouse, but intuitively and using all of the computer’s potentiality.

The goal of “making the computer disappear” (Weiser, 1991) can happen in different ways and disappearance can take different forms. As described by Streit (2001) “physical disappearance” refers to the miniaturization of devices and their integration in other everyday artifacts, as for example, in clothes, so that you don’t see them anymore. Mental disappearance refers to the situation that the artifacts can still be large but they are not perceived as computers because people discern them as, e.g., interactive walls or interactive tables. Thus, technology moves mentally into the background.¹ Two core research questions emerge: “how can we design human-information interaction and support human-human communication ... by exploiting the affordances of existing artifacts in our

environment? And, in doing so, how can we exploit the potential of computer-based, support augmenting these activities?" (Streitz, 2001⁴)

A decade later a Microsoft press notice (Microsoft, 2003) echoed Weiser: "As people find more ways to incorporate these inexpensive, flexible and infinitely customizable devices into their lives, the computers themselves will gradually "disappear" into the fabric of our lives." They are just not yet running on "inductively powered on heat and motion from their environment without batteries."

One of the ways to exploit this potential, according to Liam Bannon, director of the Interaction Design Centre, University of Limerick, is to look at the pioneering work of designers Anthony Dunne, Fiona Raby and Julian Blecker. The pair's impressive body of work has managed to "raise awareness, expose assumptions, provoke action, spark debate, and even entertain" with their notion of critical design. Julian Blecker creates "*design fictions* , artifacts that tell stories new forms of imagining and prototyping" by the blending of science fact, and science fiction.

This is the beginning of rethinking the computing paradigm and the discovery of an individual that claims a different kind of control over the machine; one of individual reciprocity. To paraphrase Mark Weiser, the idea was to take the connectivity out of the computer and put it in the very fabric of our clothes (so we get wearables), in homes (smart homes) and in cities (smart cities). In other words, let us make ourselves into a "dashboard", the environment will become the interface.

A decade after its conception the internet of things is an emerging technology yet to reach the consciousness of the masses. And yet it has a surprisingly long, even illustrious history. Radio Frequency Identification started in world war two. RAF spitfires would have active tags in the cones of their noses. Huge radio towers blasted radio waves that searched for the Spitfire signals. Friends flew, foes were downed. Access control appeared to be a logical peace time uptake of the same principle: friends open doors, foes get locked out.

⁴

Streitz, N. A., Kameas, I. Mavrommati (Eds.) (2007), *The Disappearing Computer: Interaction Design, System Infrastructures and Applications for Smart Environments. State-of-the-Art Survey*, Springer LNCS 4500

It is also an integral part of your life. Most of us carry RFID in our wallets without even acknowledging that we are engaging with network technology. But we hold the cards we use to get into the office to the RFID reader embedded in the wall near the door. This reader pushes a constant wave of energy. The antenna in the chip picks up the energy, then moves it on to the chip that says "hello". The number appears in a database and in the database one can attach any action to that number: accept as OK and allow to pass. To all extents and purposes the computer is in our pocket and yet it has disappeared from our consciousness, just in the way that Weiser and others predicted. As far back as 1999 MIT brought the cost of the tag down to below 1c (Albrecht, 2002) an important moment to start considering using RFID in a logistical ecology with barcodes and shotcodes (2 and 3D barcodes).

1.2 Early Research

The Disappearing Computer⁵ started in 2001, a cluster of 17 projects addressing a wide range of themes and issues and therefore being conducted by interdisciplinary research groups (Streitz, 2001, and Streitz, N and Nixon, P., 2005 and Streitz, N and Kameas, A, 2007)

Its mission was "to see how information technology can be diffused into everyday objects and settings, and to see how this can lead to new ways of supporting and enhancing people's lives that go above and beyond what is possible with the computer today." It hosted a wide variety of projects, such as *Workspace*, aiming "to augment the work environment through spatial computing components, initially for members of the design professions, but with applicability to a wide range of work domains."⁶, The MiME⁷ project that focuses on the relationship between computer technology and people's experience of their intimate media collections around the home, and *e-Gadgets* (e stands for extrovert) seeking "to adapt to the world of tangible objects the notions of component-based software

⁵ <http://www.disappearing-computer.net/projects.html>

⁶ <http://daimi.au.dk/workspace/index.htm>

⁷ <http://www.mimeproject.org/>

systems by transforming objects in people's everyday environment into autonomous artefacts (the eGadgets). The eGadgets range from simple objects (like tags, lights, switches, cups) to complex ones (like PDAs, stereos) and from small ones (like sensors, pens, keys, books) to large ones (like desks, TVs).⁸ The forerunner to DC was i3: Intelligent Information Interfaces⁹. The Call for i3 in 1996 read:

"The Connected Community calls for investigative research leading to new interfaces and interaction paradigms aimed at the broad population. As its focus it takes interfaces for the creation and communication of information by people, and for people and groups in a local community.

Connected Community asks projects to take on a number themes as a baseline for the research and demonstration of new interfaces, such as:

Computer Support for Real Life : thinking of ways of augmenting everyday activity rather than replacing it with a synthetic virtual one.

Territory as Interface : considering the whole territory of the community as interface and thus the relationship between real physical spaces and augmented ones.

Active Participation : making it just as easy for people to create and leave traces (of information) as it is to access that information.

The Connected Community suggests work on technologies that explore areas related to "Devices", "Information" and "Places", particularly in the context of collective use. For example, public domain devices for collective interfaces, knowledge sedimentation and adaptive databases, bulletin board agents, low-cost portable networked interfaces, wireless devices for collective use, and the linking of territory and interface. The

⁸ <http://www.extrovert-gadgets.net/>

⁹ "Intelligent Information Interfaces, or i³, is an Esprit Long-Term Research initiative. The aim of i³ (pronounced "eye-cubed") is to develop new human centred interfaces for interacting with information, aimed at the future broad population. i³ aims at a radical departure from present-day human-machine interface concepts and does this under the assumption that this can only be done guided by a long-term vision intertwining human, societal and technological factors. The initiative aims to launch research on new forms of interaction that will place people as active participants rather than passive recipients of information. "<http://cordis.europa.eu/esprit/src/eyeintro.htm>

schema also sets guidelines for projects on their *process* and evaluation."

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1.3 *Second Phase*

The second phase encompasses the period after 2005 until the present day. This section, therefore, charts the construction of the competing technologies that constitute the internet of things. It will examine the contemporary role of these new technologies and suggest how they are beginning to be used in a pragmatic sense.

There were a lot of terms around: ubicomp, ubiquitous computing, ambient intelligence, pervasive computing, things that think, calm technology, intelligent information interfaces (and so on), how come the internet of things seems to be the winner? IoT is understandable for people as it works with the metaphor of the internet. Now we have the interconnection of everything as the web of things: a layer over things. The move to the term internet of things by International Telecommunications Union (ITU, 2005) is marking the second phase.

As the terms ubicomp and pervasive computing were pushed by IBM, and ambient intelligence by Philips, these terms seem to promote industrial agency of the environment over the individual, thus raising immediate privacy issues. When engaging with these early versions of the internet of things you cannot help but ask yourself who is in control? Fuelled by logistics, supply chain management and access control, their conceptual frameworks stem from the key function of what becomes to be seen as the glue to this world in which everything is connected to everything.

If asked in 2000, why are they building this nascent internet of things? The answer would have been because companies and governments amass huge amounts of data in order to run more agile datamining algorithms to bring them more likely scenarios of the immediate future. Because data storage became so cheap (Burleson Consulting, 2007) it soon became possible to store copies of the *entire* internet. The early protests against RFID and its invisible tracking ability

¹⁰

The Connected Community has been developed by Philips International (Irene McWilliam - email c887536@nlccmail.snads.philips.nl), Domus Academy and Meru Research. <http://cordis.europa.eu/esprit/src/eyecall.htm>

(Albrecht, 2003) were directed not only against the patents of industry dug up by Katherine Albrecht in her book *Spychips*, but by the fact that this operation towards unique identifiers of all objects on earth was run as if it were an upgrade of the logistics and efficiency thinking of the barcode. There were too few stakeholders involved.

If we are asked today, why are “they” building this, we notice immediately that it becomes increasingly unclear who “they” are. As “they” are now startups companies that have their roots in artistic and design practice (such as Arduino and Pachube). In web 2.0, online social networks such as Facebook, as well as large technology corporations such as Apple, Google, IBM/Cisco, SAP, Siemens, Lufthansa, IoT Reference Architecture initiatives such as IOT-A (www.iota.eu),¹¹ in the EU Expert Group on IoT bringing a wide variety of stakeholders together . In the rapid prototyping ecology of fablabs, bricolabs and open soft- and hardware initiatives (Open NFC, 2011; Open Picus, 2011; Arduino, 2011), and projects such as Sourcemap (Sourcemap, 2011) that makes maps of the parts and source of all kinds of objects from planes to French cheese.

In April of 2010, Arrayent launched its internet-connect-your-product-in-a-day DevKit "enabling product companies to connect their products (sold at retail or Cedia channel) to web applications, smartphone and PC browsers at unprecedented low cost." Arrayent did not wait for global standards like EPC Global but decided to look at the real connectivity they wanted to offer and decided to take responsibility for every step: the tag, the reader, the database and the server.

Bob Dahlberg (VP sales of Arrayent) argued that: "There has to be business value in replacing [the] "PC in the middle" paradigm with a seamless wireless network. The obvious example is to examine what impact the Kindle has had on the e-book market, namely a 133% growth (Council, 2010). He foresees a coupling of functions, and selling "consumables", such as "air cleaners that send text messages to remind you that the filter is clogged." Brand loyalty can be build "by giving a

¹¹ In order to propose an Internet Of Things Impact Assesment procedure and format similar to the process that led to the PIA, The "[Privacy Impact Assessment Framework for RFID applications](#) " has been endorsed by the Article 29 Working Party on 11 February 2011 successfully completing a task that started nearly two years ago.

channel something more to sell, such as ongoing service. In the case of blinds, for example Designer gets notice that Mrs Jones batteries for her motorized blinds need to be changed."

This requires a different kind of trust for how can the aforementioned Mrs Jones know when her batteries are down?¹² If the company needs cash at one particular point might it not ping the batteries to send them notice? The ink cartridge industry, for example, has a very bad track record in this area, as customers realize that there is still ink in one particular color reservoir yet the software indicates that you have to replace it. Here the physical world and the virtual world do not meet and this lack of transparency has created a huge grey market.

In this second phase of internet of things we see social media and objects beginning to merge in meaningful ways. This has a playful quality to it. Facebook bought Nextstop, a user-generated travel recommendation site, in July 2010 (Gannes, 2010). Before this deal Facebook had been trying to buy Foursquare, a web and mobile application that allows registered users to connect with friends and update their location. Bearing in mind the kind of merging of functions that Arrayent is encountering as business opportunities the following scenario was very conceivable. If you "check in" from a physical location by entering into the application on your mobile phone that you are here (sort of twittering your real life coordinates) this is converted into a direct update in your online Facebook status. You "check in" your local supermarket. A feed is alerting your Facebook status. You play Mafia Wars, a popular multiplayer social network game. The game "sees" your location and Coca Cola has set up a good deal for you there. You buy one, you get two plus points in Mafia Wars.

12 "A security "noob" mistake "has left the batteries in Apple's laptops open to hacking, which could result in a bricked battery or, in a worst case scenario, fire or explosion ... Laptop batteries include microcontrollers which constantly monitor charging voltage, current, and thermal characteristics, among other properties. These microcontrollers are part of a system called the Smart Battery System, designed to improve the safety of Li-Ion and Li-Poly cells used in these batteries." (Foresman)

The tipping point¹³, as argued by Gladwell and others (Gladwell, 2000) is where minority opinion quickly becomes majority opinion, is when about 10% of a particular sphere of interest, starts to have a real belief in a particular idea, topic or trajectory. IoT seems to have reached this crucial point in 2011, at least among investors, broader non-technical opinion leaders and top and middle management of industry. Labeled the “most promising IOT startup” (MacManus, 2011) for years Pachube was bought in July 2011 by Logmein for \$15m outright. Usman Haque, founder and CEO related at Forum Europe Brussels 2011 how he preferred to stay in Europe for its rich cultural climate, high education culturally diverse young talent and politically stable climate. Yet no VC money was found in Europe.

IBM announced in July 2011 the creation of the Services Innovation Lab (SIL), a new global lab that will "initially comprise about 200 technology experts hand-picked from around the company". The lab will accelerate the expansion of “real-time analytics and software automation” in both IBM's technology services offerings and its global services delivery capabilities." (IBM 2011)

1.4 *Current Research*

The European Commission Communication on the Internet of Things¹⁴ outlines a policy framework for the IoT in Europe that identifies actions focused on Governance, privacy and protection of personal data, security, the silence of the chips, and global institutional awareness.

¹³ Scientists at Rensselaer Polytechnic Institute have found that when just 10 percent of the population holds an unshakable belief, their belief will always be adopted by the majority of the society. The findings were published in the July 22, 2011, early online edition of the journal *Physical Review E* in an article titled "Social consensus through the influence of committed minorities." The research has broad implications for understanding how opinion spreads." (Physorg, 2011)

¹⁴ COM(2009)278final,
http://ec.europa.eu/information_society/policy/rfid/documents/commiot2009.pdf

The European Research Cluster on the Internet of Things (IERC) is sponsored by the European Commission's Seventh Framework Programme. It focuses on enhancing Europe's competitiveness in the information society, as well as exchanges in best practice sharing at an international level on IoT matters (IERC, 2011). In a separate development, the UK government has allocated a £5m (\$8.3m) grant to develop the IoT in the UK. Hosted by the EU's Seventh Framework Programme and the European Lighthouse Integrated Project is the "Internet of Things Architecture" (IoT-A) project. IoT-A addresses the Reference Model and possibly several Reference Architectures related to the IoT domain. IoT-A plans to generate different reference architectures according to abstract requirements for the technology, creating design guidelines for real systems. At the same time, real end-users and real applications will provide precise domain-specific requirements, which will drive theoretical work. Key EU research issues are discussed at the IERC IOT week.¹⁵

Patrick Guillemin of Strategy & New Initiatives, ETSI sees IoT as a system of systems, a network of networks and although the challenges are huge as the terrain is so big: FP7 research, RFID Mandate, IoT/RFID, ISGF AFI M2M through initiatives like Casagras 1 and 2 there are timely standardisation debates going on. We tend to look from the rear view mirror so the challenge with all policy makers in this dynamic and exciting time is to be careful before we legislate and lock in. It is important to realise that in Europe IoT did not simply 'pop up'. The work of EU research, from i3 (Intelligent Information Interfaces), Future and Emergent Technologies through more specific programs such as Casagras has been very deliberate. The past decade has also shown that there will not be one technical standard for IoT but several generic numbering schemes, which makes the role of middleware, interfaces and open standards of paramount importance. The key factor of openness was very present in the discussion that followed. iUD in Japan was very much a result of the openness of the infrastructure and platform together with the very strong links between academic research and industry R&D successful cases, favouring, as Ken Sakamura, originator of iUD stated, not a de jus, but a de facto, more informal environment. (van Kranenburg 2010)

¹⁵ The IoT Week is an event organised together with four European Projects, IoT-A, IoT-i, CASAGRAS2, SMART SANTANDER and with the support of the European Research Cluster on Internet of Things (IERC). It is held twice a year. For the calendar see <http://www.internet-of-things-research.eu/events.htm> For more information, please contact us at info@internet-of-things-research.eu.

The Annual Internet of Things Europe 2011 Conference¹⁶ (going into its fourth year), "run with the support of the European Commission, joined together business leaders, consumer advocates, policymakers and entrepreneurs to explore what opportunities and risks the Internet of Things will offer businesses and consumers." These kinds of meetings become more important as the stakeholders become more varied, unschooled in bureaucratic processes, less formal and less hidden from public view.

The barcode was negotiated by standard organizations that brought thousands of companies and a great number of application, service, infrastructure and hardware layers together. It "forced" companies not to compete on that particular level. Much like the generic container that enabled global supply chains, all trucks and container boats share the same identical footprint that allows quick transfers and easy stacking of many different goods. With these technical protocols we offload the economic and ecological impacts to the beginning of the supply chain and people only see the cheap end products.

The story of the current RFID standard called "EPC Global" - is the story of two standard bodies EAN and UCC merging to become GS1 in 2005. In a bold move that no regulator foresaw, they scaled their unit of data from being in a batch of 10,000 and thus uninteresting for individual consumers to that of the uniquely identifiable item. Holding your phone to a package of coffee not only gives you info on where it came from, how green it is, but also who, in your social network on LinkedIn or Facebook, is buying it. From a very mundane and "dull" logistics tracker of batches of goods they are now enablers of rich information that can potentially target individual people in their consuming, informational and social habits. GS1 is now potentially a *media* company.

IoT labels are informing debates on smart metering and smart grids thus deeply influencing the way sustainability and cutting back on energy consumption is

¹⁶ See also The 2nd Annual Conference Internet of Things Europe 2010 Report. Held on 1st and 2nd June 2010

The Crowne Plaza - Le Palace, Brussel. A Roadmap for Europe This report of the conference has been written by Rob van Kranenburg, Conference chair
ec.europa.eu/information_society/policy/.../iotconferencereport2010.pdf

shaping the pilots on the EU FIRE testbeds and in developing smart cities. IoT is seen to be more as an enabler of Cloud computing, as the predictions of scale (Cisco predicts 50 billion connected objects by 2020) of data generation by passive and active sensors, requires new balances between human intervention and planning and autonomous M2M operations. IoT has been mentioned by the Chinese Premier Wen Jiabo as a political project of gaining insight into natural, socio-cultural and business processes by building a Sensing Planet, thus providing a dashboard for planners. The EU FP7 Security program consists of over fifty projects that use smart camera's, bio bom detectors, integrators for planners and event managers (World Cups, Olympics, Champions League) that are fuelled by notions of smart surveillance.

Talbot (2011) points to the 'inherent power, sensing and location-finding capacities, access to internet-based the cloud services and burgeoning popularity of NFC-equipped mobile phones, and their ability to target advertising, translate text, check into flights, buses or metros, make photo analysis, data bumping on phones, allow people to broadcast their location in order to meet, and make payments." These services are made available through technology, such as GPS chips, location identifiers based on Wi-Fi signal strength, and cameras (Talbot, 2011). It is forecasted that NFC will spearhead machine-to-machine (M2M), or IoT, development (China Communication Network, 2011).

Big Brother vs. Empowerment

"One of the biggest themes of the 21st century is interconnection — specifically, the interconnection of people and data. These interconnections can change everything about how we see the world, how the world sees us, and how we work together. Where some people might see "big brother," I see empowerment — empowerment of groups and individuals to improve quality of life and reduce our impact on the planet. - Megan Smith Vice President, New Business Development Google, January 28, 2010

A debate in the Netherlands on privacy and data protection was sparked by the introduction of the OV card, the RFID chip travel card - after it became known that the Mifare chip it contained was hacked yet this did not stop the project. Pachube, a web-based service built to manage the world's real-time data ("patch-bay") was beta until 2010. In a very short space in time it became an instigator, as well as a hub and a driver for the Open Data movement, "as the Fukushima disaster has touched off concern worldwide by showing the need for governments to provide data in open, accessible formats." (Steinbach, Marian. pachube blog 25 July 2011).

Florian Michahelles and Andrea Girardelle (2010) discuss *TwiPhone*, a mobile app that posts mobile phone event data, such as time and caller ID, as well as SMS communication, including text contents, to Twitter. According to Girardello, this "essentially meaningless application, which seems nightmarish for privacy advocates, has surprisingly been downloaded by several thousand Android users." It is used by several hundred people whose conversations can be publicly retrieved onTwitter using the #twiphone hashtag: "Do users not care about privacy anymore, or are they just unaware? Is privacy becoming an optional feature?"

Gary Wolf - with Keyin Kelly - one of the founders of the Quantified Self explains in *Data Drive Life*¹⁷ argues that until a few years ago - it would have been pointless to seek self-knowledge through numbers:

"Although sociologists could survey us in aggregate, and laboratory psychologists could do clever experiments with volunteer subjects, the real way we ate, played, talked and loved left only the faintest measurable trace. Our only method of tracking ourselves was to notice what we were doing and write it down. But even this written record couldn't be analyzed objectively without laborious processing and analysis. Then four things changed. First, electronic sensors got smaller and better. Second, people started carrying powerful computing devices, typically disguised as

¹⁷ Wolf, Gary. *The Data Driven Life*, April 28 2010. <http://www.nytimes.com/2010/05/02/magazine/02self-measurement-t.html?pagewanted=2>

mobile phones. Third, social media made it seem normal to share everything. And fourth, we began to get an inkling of the rise of a global superintelligence known as the cloud."

MIT researcher Deb Roy¹⁸ wanted to understand how his infant son learned language -- so he wired up his house with videocameras to catch every moment (with exceptions) of his son's life, then parsed 90,000 hours of home video to watch "gaaaa" slowly turn into "water." Moodscope¹⁹ looks at how Weight Watchers works. Members log their weight regularly and share it with others who support and encourage them. They argue that scientific research has shown that this really succeeds," so could something similar work to manage moods?"

Ratto and van Kranenburg state that the internet and the IoT enable mass participation of growing groups of individuals in what used to be macroeconomic issues: energy (coupling smart meters, production of goods (Reprap, fablabs et al)), communication (open content, software, hardware and networks). Broader question for future research include how far these trends -- that are global - could affect planning and large architectural projects: mobility, transport (mapping on different data, construction and community co-design). Ratto and van Kranenburg propose the creation of a infrastructure of generic information through the development of shared and open hardware and software test beds for experimentation and a supportive online space for the sharing of questions, "how-tos", problems, and results. They call this loosely organized set of already existing bottom-up techno-cultural labs, R&D institutes, academic labs and research, and open source hardware initiatives bricolabs (see www.bricolabs.net), in order to celebrate their ad-hoc, experimental nature, and their emphasis on practices of reworking, redoing, and "making do".

¹⁸ Deb Roy, The Birth of a Word (March 2011, TED)
http://www.ted.com/talks/deb_roy_the_birth_of_a_word.html

¹⁹ <http://www.moodscope.com/> See also Sleep measurement Fitbit, Zeo <http://www.fitbit.com/>
<http://www.myzeo.com/> Exercise tracking, Runkeeper <http://runkeeper.com> Weight management, Withings <http://www.withings.com/en/bodyweight>

When we think of infrastructural projects, we think “big, “scale, “expensive, “complex” and “central. Is it possible to address things such as roads, sewage systems and other infrastructural requirements in a decentralized way while still keeping the balance in costs, productivity and energy efficiency? Can infrastructural projects be crowdsourced? This was the subject of a Council workshop in the Picnic festival (2011). Festivals like Picnic, Isea, Transmediale, Lift, RIXC, DEAF, Future Everything, Pixelache, Scrapyard Challenges -- and local dorkbots -- have greatly accelerated the playful adoption of open source software (Processing) and hardware (Arduino -- an open-source electronic prototyping platform) and have facilitated debate and discussion on smart objects and environments among hackers, designers, thinkers and tinkerers. The first Conference to address the Design Challenge of Pervasive Computing was Doors of Perception, Flow 2002. Neil Gershenfeld²⁰, Bruce Sterling, John Thackara²¹, Malcom McCullough²², Esther Polak²³ as well as Usman Haque were among the

²⁰ Prof. Neil Gershenfeld Director, The Center for Bits and Atoms, MIT. Author of When things start to think, Neil A Gershenfeld, 2000. Holt Paperbacks.

²¹ author of In the Bubble: Designing in a Complex World. Cambridge, Mass: MIT Press, 2005 www.thackara.com/inthebubble/

²² Digital Ground Architecture, Pervasive Computing, and Environmental Knowing, October 2005. ISBN-10: 0-262-63327-2 ISBN-13: 978-0-262-63327-7 Digital Ground is an architect's response to the design challenge posed by pervasive computing. One century into the electronic age, people have become accustomed to interacting indirectly, mediated through networks. But now as digital technology becomes invisibly embedded in everyday things, even more activities become mediated, and networks extend rather than replace architecture.

²³ Esther Polak showed one of the first location based art works: " In our everyday life, we usually follow fixed paths and trajectories throughout the day: from our home to work or school, to family, to familiar stores and to places where we spend our free time. We all have invisible maps in our head: of our immediate surroundings and of the roads we take every day. The way we move around in the city, and the choices we make in this process, are determined by this mental map. For the exhibition 'Maps of Amsterdam 1866-2000', Waag Society and Esther Polak together with Jeroen Kee were invited by the Amsterdam City Archive to produce a work about mental maps in that city: 'Amsterdam RealTime'. During two months, 75 volunteers were tracked by GPS in their everyday movements and routines around

speakers. Pachube, recently acquired by LogMeIN for \$15 million, headed by architect designer Usman Haque stems from sensor based projects that circulated and grew in this environment (Haque, 2011). A diverse array of projects including, FabLabs, maker communities, the pontos de cultura in Brazil, co-working Design studios and others (citizen science, DIYbio) have grown in numbers in recent years and enhance both citizenship and democracy but also the innovation potential through an active and direct involvement of citizens in the R&D process, not least in term of translational and participatory research. Supportive of both science and technology literacy as much as of citizen power, they aim to involve people directly in the design and R&D phase of technology but also in the political, legal, and ethical issues related to the adoption of emergent technologies."²⁴

the city. These traces were then drawn as white lines over a black background. The resulting, animated map has a distinct look and feel of psychogeographic experience: it is not precise or rational, but expresses the intuitive and personal aspects of geography. It shows a city that does not consist of buildings, roads and water, but of the movement of its inhabitants. Thicker and brighter lines indicate greater frequency of travel. The map also was influenced by the variety of means of transportation: a cyclist will produce completely different traces than someone who drives a car. Once the participants became aware of their mapping outcomes, some even attempted to create artful GPS drawings. Interestingly, the final, combined map of all individual traces resembles an objective city map again. " <http://realtime.waag.org/>

24 This is the subject of the research of Denisa Kera who has received a modest research grant from the Singapore government to investigate where innovation comes from in the current networked reality.

2. Technological Challenges and Foundations

The technological domain of the internet of things (IoT) embraces several developments, as disjointed as they are numerous. As the definition itself is still under heavy discussion, as we saw in the earlier section, it is quite difficult, even tricky, to set boundaries, in order to determine clearly which technologies are within its range. Considering, for the sake of brevity, that IoT is built by "interconnected smart objects", we can orientate our interest more towards communication technologies, developing the way this connection is established, or else consider the "smart object" perspective, in which for instance, developments related to energy harvesting and conservation, as well as the miniaturisation of printed circuits, and inclusion of transistors into commonly used materials such as plastic, wood or metals are of central importance.

Foundations

In any case, starting from the architectural level until the devices, a wide range of current technologies is labeled "IoT". Regarding architectures, several public funded projects, especially in the EU, have attempted to set common reference models and/or architectures. The EU project IoT-A produced a publicly available deliverable highlighting in details the IoT state of the art [IoT-A, 2011]. In general, for IoT Architecture we mean an integration of heterogeneous wireless sensor and actuator networks (WS&AN) into a common framework of global scale and made available to services and applications via universal service interfaces. The EU project SENSEI aimed at creating an open, business driven architecture addressing the scalability problems for a large number of globally distributed WS&AN devices.

To enable RFID and EPCglobal standard solutions in practice, technical, social and educational constraints - particularly in the area of security must be overcome. BRIDGE (Building Radio frequency IDentification solutions for the Global Environment) addresses these problems by extending the EPC network architecture [Bridge, 2011]. This is done by researching, developing and implementing tools which will enable the deployment of EPCglobal applications in Europe. The "enablement" is mostly in the development of security apparatus, both in hardware, software and business practises.

The Cross UBiQuituous Platform (CUBIQ) [CUBIQ 2010] project aims to develop a common platform that facilitates the development of context-aware applications. The idea is to provide an integrated platform that offers unified data access, processing and service federation on top of existing, heterogeneous ubiquitous services. The CUBIQ architecture [Dempo, 2010] consists of three layers: (1) a data resource layer, (2) an intra-context processing layer and (3) an inter-context processing layer. The data resource layer provides transparent data access and handles mobility, migration, replication, concurrency, faults and persistency. The intra-context layer provides data processing services. The inter-context processing layer is responsible for service composition. The CUBIQ architecture provides interfaces for each layer.

Beside the results coming from those research efforts, there are several architectures currently used in several commercial products. Zigbee [Ashton, 2009], developed by the Zigbee Alliance is probably the most popular one, as it's a simpler, more scalable alternative to Bluetooth.

WirelessHART, extension of the popular HART (Highway Addressable Remote Transducer) communication technology, provides several features such as security and robustness, but provides no interoperability with other communication technologies because of its single-purpose philosophy [Mindtech, 2009; Song, 2008]

Sun SPOTs are a platform from Sun Microsystems for the development of sensor networks and embedded systems. Sun SPOT is an acronym that stands for Sun Small Programmable Object Technology [Sunspot, 2010]

REST is a coordinated set of architectural constraints that attempts to minimize latency and network communication, while at the same time maximizing the independence and scalability of component implementations. This is achieved by placing constraints on connector semantics, where other styles have focused on component semantics [Fielding, 2000]. REST enables the caching and reuse of interactions, dynamic substitutability of components, and processing of actions by intermediaries, in order to meet the needs of an Internet-scale distributed hypermedia system. REST elaborates only those portions of the architecture that are considered essential for Internet-scale distributed hypermedia interaction.

Regarding communication protocols, several solutions have been developed to overcome the limitations of current network technologies. Stream Control Transmission Protocol (SCTP) [Stewart, 2000] is an IETF proposed standard

protocol for the transport layer. It is designed to eventually replace TCP and perhaps also UDP. Like TCP, SCTP is reliable but offers new features such as multi-streaming and multi-homing. In particular, the multi-homing feature of SCTP enables it to be used for mobility support, without any special router agents in the network. Other features included in SCTP are error-free and non-duplicated data transfer, network-level fault tolerance through supporting of multi-homing, and resistance to flooding or masquerade attacks.

The Host Identity Protocol (HIP) [Moskowitz, 2006] is a solution that locates the mobility between the network and transport layers. HIP introduces a new Host Identity layer (layer 3.5) between the IP layer (layer 3) and the upper layers. The reason for this is to avoid the situation where binding sockets to IP addresses forces the address into a dual role of endpoint and forwarding identifier. In HIP, upper layer sockets are bound to Host Identities (HI, identifiers) instead of IP addresses. In addition, the binding of these host identities to IP addresses (the locators) is done dynamically. The purpose of HI is to support trust between systems, enhance mobility, and greatly reduce the Denial-of-Service (DoS) attacks.

The Mobile IP protocol is an IETF proposed standard that provides a network layer solution to node mobility across IPv4 (Mobile IPv4, [Perkins, 2002]) and IPv6 (Mobile IPv6, [Johnson, 2004]) networks. Mobile IP allows a node to change its point of attachment to the Internet without needing to change its IP address. This is not simply a configuration simplification, but can facilitate continuous application-level connectivity as the node moves from point to point.

Using Mobile IP, it is possible to move a single IP device from point to point on the Internet without losing higher level connections. However, with the proliferation of IP and the desire to always remain connected to the Internet, we are seeing entire networks of IP devices moving together from one place to another. It is possible to enable mobility for all of these devices using standard Mobile IP; however, this would require all devices to be capable of Mobile IP and generate excess overhead as every device would have to perform Mobile IP functions.

Another solution to the problem is Network Mobility (NEMO) [Devarapalli, 2005]. NEMO works by moving the mobility functionality from Mobile IP mobile nodes to a moving network's router. The router is able to change its attachment point to the Internet in a manner that is transparent to attached nodes. NEMO is

an extension of Mobile IP that enables an entire network to change its attachment point to the Internet.

In the IoT domain, smart objects and services exploiting them are distributed globally.

Thus, there must be a sort of identification and resolution infrastructure to discover and lookup the services that allow accessing information about smart objects as well as controlling them. Resource Identification can essentially encompass both the naming and addressing of a resource, or either of them. In the Web, the identification of a resource that represents some form of information has been achieved by the development of the Universal Resource Identifier (URI) [W3, 2004], which is a global agreement on the identification of a particular resource based on specified schemes. In IoT, similar to the Internet and the Web, objects and resources need to have common naming and addressing schemes and also discovery services to enable global reference and access to them.

In SENSEI [Much-Ellingsen, 2011], the resource ID is formed through a concatenation of several parameters; the domain of resource's provider, the type of device, a name representative of the resource's function, and a unique identifier that differentiates the resource from others of the same device type. In the Ubiquitous ID (uID) framework [uID, 2011] identification is represented by the 'uCode', which is a unique identifier for either physical or logical entities. The uCode itself is a 128-bit number that has no relationship to what it represents, but rather the relationship is retrieved from dedicated database servers. The structure of the uCode is formed in a manner to support its management.

In the field of RFIDs, EPCglobal [EPCglobal, 2005] have promoted the adoption and standardization of Electronic Product Code (EPC), which has been used as a means of uniquely identifying RFID tags. It is based on the URI model. ID@URI developed by the DIALOG research project [Dialog, 2011] is also another identification model that takes the same properties of the EPC/ONS standard but can also be manifested in barcodes as well.

The Internet in the Internet of Things

Whatever the perspective, though, there is a need for substantial progress in research achievements in several fields. Firstly, today there is no single way of

identifying an object in the internet of things: there are several standards, such as 2-D bar codes, GS1, uID, IPv6 addresses, but they are non-compatible. Moreover, reference architectures which can lead the way to any kind of real-life system implementation must be identified and standardised. As well, security mechanisms should ensure reasonable safety and privacy properties. Communication protocols, from physical layer to interfaces with services and applications, need substantial advances in order to leverage the upcoming of any IoT vision. The above are just a few examples of areas of research that need substantial development in the coming five to 10 years.

Physical communication interface type	Communication type	Protocols	OSI Layer
802.15.X Series (ZigBee, Bluetooth, RFID, etc)	Wireless	NWK/APS/API defined by each standardisation body (all non-IP)	Network/Transport/upper
WiFi	Wireless	IP/TCP-UDP	Network/Transport/upper
UWB	Wireless	Baseband/LinkManager/L2CAP (non-IP)	Network/Transport/upper
Sensor network busses (e.g. CAN, Profibus, etc)	Fixed	Up to data link	Data Link
Serial	Fixed	Up to data Link	Data Link
USB	Fixed, Wireless	Up to Data Link	Data Link
DeviceNet	Fixed	DeviceNet network and transport	Network/Transport/upper
ControlNet	Fixed	ControlNet network and transport	Network/Transport/upper
Ethernet/IP	Fixed	IP/TCP-UDP	Network/Transport/upper
Power line (KNX, LonWorks)	Fixed	Network/transport layers according Network layer/Transport to KNX and LonWorks specifications	Network/Transport

Table 1: Protocols of popular physical communication interfaces exploited by communication-enabled objects

Within the "internet" side of IoT, which is dealing with communication between objects, there is a need to develop a convergence between different communication means. Today several communication mechanisms (as shown in

the table 1) are deployed in current applications, and any novel technologies will need to guarantee interoperability between different protocols. We must also consider that the lifetime of network technologies might be much shorter than the one of the physical objects connected to it, where that same technology is applied. In the “common” internet, the interoperability between low-layers technology and services is assured by the use of the Internet Protocol (IP). Usually, the network technologies are represented in an “hourglass” shape, with the IP layer in the middle, and this is commonly referred as "the narrow waist" of internet. The questions of what shape the IoT “narrow waist” will have -- and even if such a thing will exist considering the heterogeneity of IoT technologies -- are of primary importance, and future research should clearly focus on them. Just to make an example of the complexity we face, if we describe the communication layers in the classic way, we could imagine a "thin layer", just below the service and application layers and above all the different technologies used to transfer information, as the glue of different solutions developed for a specific target using very specific technologies. However, such a solution is clearly simplistic, as we would then need high-level gateways between different technology silos, and this would not make any sense from not only from the technological point of view, but first and foremost from the economical point of view.

Regarding security issues of communicating objects, a significant research effort (Internet Security Group, 2011) has been undertaken on cryptography tailored for low-cost, low-throughput, resource-constraint devices. This domain has been referred to as “light-weight cryptography”, and has produced a number of new protocols have been proposed for small devices, such as RFID tags (Internet Security Group, 2011). In spite of the large number of available methods, there are very few which have been examined enough to be considered safe.

In the past years, a few light cryptography algorithms that have been widely deployed were proven vulnerable such as, for instance, the well known case of MiFare Crypto-1 (Garcia, de Konig Gans, Muijers, van Rossum et al, 2005). The development of light cryptography standards is paramount for the wide-spread adoption of IoT technologies.

In addition, the combination of light-weight cryptography protocols for use of light duty devices and regular cryptography framework such as Public Key

Infrastructure (PKI) for back-end infrastructures should be analyzed. A very important consideration in this is key management: such a holistic framework should identify the actors generating the encryption keys, in case of private/public keys schemes, how these will be distributed and who (which agencies/companies/authorities) will eventually be given access to such keys when necessary.

In the following table, we will produce a synthesis of common threats per network communication layer, to give the reader an initial idea of the vulnerabilities that IoT systems face.

Layer	Threat	Requirements	Targets[1]	Approaches
Transport	Ping/ICMP flood	attacker being part of the network, ICMP	All connected devices	
	Synflood	TCP, attacker being part of the network	All connected devices	
Network	Neighbor discovery attack	Neighbor Discovery protocol	Networks using unauthenticated ND protocol	Authentication support for ND protocols
	Wormhole	Mesh networking	Multihop wireless networks	Specific hardware, time constraints on packet delivery
	Black hole	Attacker being part of the network	Multihop wireless networks	Don't use plain distance-vector based protocols.
Link	Spoofing	-	All networks, especially wireless	Packet authentication
	Eavesdropping	-	Wireless networks	Encryption
	DoS – Collision	-	Wireless networks	Use UWB, increase data rate
	DoS – Exhaustion	-	Embedded wireless networks	Link-layer Intrusion detection
	Replay protection att.	Replay protection	Multihop wireless networks	RANBAR, Tesla

Fig. 3: Network Layers and Common Threats

Breaking the Unbreakable: The End-to-End Principle

The internet as we know today is based on a few, very simple and very meaningful principles. One of those is the "end-to-end" principle: keeping the technologies in the network very simple and dealing with complexity at the end points only, allowed the Internet architecture to be very scalable (Carpenter, 1996).

With regards to the IoT domain, there might be a different point of view. First of all, it has to be considered up to what extent IP technology will be used. While many technologists believe that IP will finally be on each and every smart device (Ipsos, 2011), there are two particular cases which show the likeliness that different solutions are necessary. Firstly, real-time devices, such as braking systems in cars, which cannot be based on best-effort, connectionless, unreliable protocol (as the IP is, by definition). Secondly, tiny, extremely cheap devices, (such as passive RFID tags) which may be stateless and therefore cannot use complex protocols such as IP.

Moreover, it is questionable if the end-to-end principle can (and will) be used in the IoT domain. As the end points of IoT can be extremely simple (as a temperature sensor), even if they will be able to use the IP protocol it is unlikely that they will be able to deal with complexity. Moreover, smart devices do not necessarily need to speak the same language: a medical device such as a nanorobot used to fight cancer cells in the human body has totally different needs than those of a smart fabric needing to communicate its characteristics to a washing machine. Therefore, it is likely that, at some layer, there will be bridges between systems; and these bridges (or gateways) might be considered the end-to-end points between communicating entities. In other words, between two different objects communicating, the communication path may be broken into different sections (object-to-gateway, gateway-to-gateway, gateway-to-object). As this is considered a "curse" in today's internet, and is likely to be a highly controversial topic, there is a strong need to further investigate this matter, and to come up with a commonly accepted set of founding principles.

The Things in the Internet of Things

With regard to smart objects, there seem to be the two main research axes to be developed: energy harvesting and conservation, and integration of smart components into materials.

Firstly, regarding energy, in all its phases of harvesting, conservation and consumption, there is a need to develop solutions with the objective of developing a level of entropy as close as possible to zero. Common objects, such a mobile

phone, should be able to harvest the energy they need, whether by photo-voltaic cells, or transforming the vibrations and motion into electric energy. Current technology development is inadequate in this respect and existing processing power and energy capacity is too low to cope with future needs. The development of new and more efficient and compact energy storage sources such as batteries, fuel cells, and printed/polymer batteries etc, as well as new energy generation devices coupling energy transmission methods or energy harvesting using energy conversion, will be the key factors for the roll out of autonomous wireless smart systems, which will be the backbone of IoT.

The second axe of technological development in the area of smart objects, however, is one step further. The integration of chips and antennas into non-standard substrates, such as textiles and paper, will become mainstream technologies in the coming years. Metal laminates and new substrates based on polymer with conducting paths and bonding materials, better adapted to harsh environments and environmentally friendly disposal, will become as commonplace as silicon is today. RFID inlays will be used to connect the integrated circuit chip and antenna in order to produce a variety of shapes and sizes of labels, instead of direct mounting. Inductive or capacitive coupling of specifically designed strap-like antennas will avoid galvanic interconnection and thus increase reliability and allow even faster production processes. The target must be to physically integrate the RFID structure with the material of the object to be identified, in such a way as to enable the object to physically act as the antenna. Looking back few years ago, there was a huge hype in polymer RFID prototyping, with companies such as PolyIC (PolyIC, 2004) and Philips (Philips, 2006) demonstrating fully polymer RFID tags. In parallel, silicon ultra-thin structures, such as the Hitachi mu-chip (Hitachi, 2007)²⁵, need to be developed, with regards not only to further miniaturisation, but especially to resistance to harsh environments and packaging, in order to be included in commonly used objects.

²⁵

(PolyIC, 2004): <http://www.printedelectronicsworld.com/articles/polyic-demonstrate-polymer-driven-rfid-tag-00000091.asp?sessionid=1>

(Philips, 2006): <http://www.rfidjournal.com/article/view/2139>

(Hitachi, 2007): <http://www.technovelgy.com/ct/Science-Fiction-News.asp?NewsNum=939>

Finally, it is necessary to spend a few words on the meaning of the word "smart", used extensively in this field. A smart object is commonly called a device able to sense or interact with the environment, and uniquely identifiable. Smart is synonym of "intelligent", which comes from the Latin "inter" and "legere": literally, to read between [the lines]. As this practically means to be able to interpret, we can easily see that it has a very strong non-deterministic component. To show this fact in practical terms, let us imagine two people, both of whom are very intelligent. We might expect that they would share the same opinion quite seldom and both sides normally have their valid reasons. Many, if not all of us, experienced (or, better, suffered) from non-deterministic behaviour of computers; however, glorifying the capacity of objects to self-determine their actions is probably not the target of the work in this area. While we do not propose in this document an alternative expression, we strongly feel that the use of "smart" should be carefully thought through.

State of the Art and Beyond

If we consider the IoT domain in its entirety, there are several risks to be addressed. Architectural and modelling issues for the IoT are extremely important for its success. Internet became the global phenomenon we know today when a single technology, based on a very simple and straight-forward architecture, became the standard: the TCP/IP protocol stack (Kale, 1991).

Without a clear communication model, it is doubtful that we would have had the internet revolution. Currently, we are in a situation similar to the internet infancy: the presence of vertical solutions, conceived to work in isolation for a specific applications, is generating interoperability issues and slowing down the uptake of IoT technologies.

Orchestration, management and monitoring of devices are a very important field of research, as the number of interconnected objects is supposed to reach several hundred billions (Jefferies 2007 and Clark, Partridge, Braden, Davie et al, 2005). Regarding security and privacy aspects, we can list at least two major ones, and explore the policy implications in detail in the subsequent chapter.

In the IoT general domain, the collection of data and profiling are both demonstrable facts [Hildebrand, 2010] [Langheinrich, 2009]. We can interpret this as an intrusion in private life, implementing a kind-of "big brother" control, which

gives a very negative perception. The intentions of data collection might be positive, as social sorting enables governments and companies to more efficiently provide services and to better target citizens who might be at risk. However, an excessive use of these technologies will inevitably lead to practices for commercial or other purposes, leading to exclusion of people from accessing services. Like repurposing of data and mission creep, using information for purposes that go beyond the original reason for collecting them, social sorting is an increasing temptation with increasing data collection. Consumers groups targeted because they offer better commercial prospects inevitably means that other consumers are ignored or marginalised.

Social sorting enables many enterprises, such as insurance companies or airlines, to provide some deals to their valued customers and not to others. In the long run, social sorting risks damaging notions of equality and democracy.

Technologies referred to in IoT, such as biometric related devices, may exclude by their nature of how they function categories of people. Both the very old and the young may have problems with fingerprinting or iris scans: the fingerprints might be unreadable, and the iris might be damaged.

Profiling and data mining within any IoT scenario is massively increased as a potential harm to individuals due to the ease to which data can be collected, stored, shared and analysed. Over-reliance on the content of databases (such as security related ones) may likewise be problematic in instances where mistakes are made. Individual access to remedy incorrect data being stored should be seen as a key goal yet it represents a challenge given the wide range of potential databases that might be in existence with the widespread implementation of IoT technologies and systems.

Furthermore, computer, network infrastructure or process failures can lead to a major paralysis of the overall automated IoT vision of the future. This includes both the wired and wireless infrastructure as well as critical components such as routers or back-end servers. Many, if not all, sensors and readers require wired or wireless infrastructure to deliver their data. Additionally, any system may require network access to backend servers. The current internet infrastructure is an integral part of providing future IoT services. Depending on the degree of computing network infrastructure failure, the impact to any kind of service, including life-threatening ones, could be severe.

An important factor that makes this failure even more severe and more likely is the excessive reliance on the technological infrastructure that is characteristic of this new envisaged environment. There may be an over-reliance on smart devices as the foundation of future IoT services. This can become evident in the event of an overall system failure due to compromise of these smart devices and loss of functionality due to wireless/IT infrastructure failure, equipment/reader malfunctions, theft, devices' weak access control, jamming, and social engineering or cyber attacks.

Over-reliance may also become apparent with paralysis and interruption of the future process resulting from malfunction of critical technology components such as barcode scanners, RFID tags and RFID readers due to electro-magnetic interference, vibration and age. As in the case of authentication via biometric authentication, fingerprint and iris scanners may be ineffective to, say, elderly passengers or people with finger injury or damage. Such risks arise from non-malicious "malfunction" of biometric sensors and are facts of technology limitations. Manual processes have to be devised to address them.

Hard failures could result from hardware such as kiosks, terminals, readers, RFID malfunctions, virus attacks, denial-of-service/flood attacks or drive-by downloads of malicious code. Also, for portable devices, the battery could be discharged rendering the device useless.

Many of tomorrow's facilities can and will be integrated with IoT of the future. For example, Air conditioning/heating systems, as well as plumbing systems, can be integrated with various temperature, vibration or pressure sensors at strategic locations. Data from these sensors could be read or accessed through mobile RFID readers or smart phones. Under such circumstances, the physical failure of the facilities is tightly linked with the management of the IoT devices, in addition to risks arising from structural, electrical or terrorist causes.

The research community is pushing towards a convergence between the IoT and the cloud computing domain (Caprio, 2010). However, the two concepts are disjointed. To mix a metaphor, the cloud is about transparency: an application does not care where the data is stored or computing cycles executed, but what matters is to be connected to a theoretically unlimited computing and storage capabilities, and the technological ability of transferring terabyte torrents between data centres. With IoT devices, we get into the tiniest object, and the ability of

identifying, sensing and controlling every single component. Therefore, the focus is not the same, while, the sheer amount of data generated by IoT devices will make the use of clouds indispensable, whichever the particular architecture chosen.

3. Policy

We are in the midst of a paradigm shift in computing from a centralized network model to a model of distributed computing where applications that used to run on the desktop now run in the cloud.²⁶ This shift has profound implications for privacy as the Internet of Things develops.

The foundations of privacy regulation were created 30 years ago when information technology was centralized and hierarchical. With a great deal of effort, one could ascertain who was collecting information, who controlled the information, and who one had to deal with to ensure that the information was being handled appropriately. That's no longer the case today. The tension between protecting privacy in a distributed computing model must build upon important privacy principles that have emerged over the last thirty years. However, applying long standing privacy principles will be challenging in a world of distributed computing.

The Role of RFID

Radio Frequency Identification (RFID) technology is one of many IoT enabling identification technologies, and not necessarily the main one. There are several technologies that may be encompassed in an "Internet of Things" including identification technologies, Near Field Communications (NFC) technologies, wireless sensor and smart technologies. However, RFID represents a small aspect of the overall debate since the IoT will mainly consist of smart objects e.g. all forms of sensors, actuators, small devices connected together using radio technologies but also wired technologies. IoT applications will be used in a wide range of innovative areas like industrial automation, smart grids, smart cities, home and building automation to name a few. In this sense, the IoT can be considered as an evolutionary process not as something completely new.

²⁶ McGuigan, Brendan 2011, What is Distributed Computing, Wisegeek <http://www.wisegeek.com/what-is-distributed-computing.htm>

For instance, Cisco²⁷ foresees the IoT and the number of devices connected to the Internet exceeding the number of people populating the entire planet. And that's not just smart phones and tablets. Its sensors enabling a smart grid, smarter transportation flows, tracking the health of cattle, and medical devices monitoring the health of cardiac patients. Rather than always interacting with humans, sensors will be interacting with each other automatically, updating our daily schedules. Devices will, for the most part, be mitigated through local area networks. It's true that devices will have a unique IP address in an IPv6 world. However, the business case does not yet support independent communication of every tagged item.

Protecting Privacy and Enabling Innovation

A policy debate on the IoT needs to include discussions on all technologies that enable this "ecosystem." Such a broad multi-stakeholder discussion needs to include the importance of the transatlantic dialogue and be informed by the review of the EU Data Directive, and legislative and regulatory debate around privacy and mobile applications taking place in the US and Europe. Global policy approaches need to avoid technology specific silos where specific technology is regulated separately. A broader technology policy approach that is horizontal in nature must be considered to include other important issues like cloud computing

Although there are self-evident societal benefits to individuals from this computing continuum, these "smart/connected" devices present privacy and security challenges, as well as opportunities, which require an examination of the underpinning of the 1980 OECD²⁸ privacy guidelines known as the Fair Information Principles (FIPPS).

The OECD Privacy Guidelines: Fair Information Principles (FIPPS)

²⁷ Evans, Dave 2010 Infographics <http://blogs.cisco.com/news/the-internet-of-things-infographic/>

²⁸ OECD Guidelines on the Protection of Privacy and Transborder Flows of Personal Data: Background

The core FIPPS address the following principles:

Notice/Awareness: The most fundamental principle is notice. Consumers should be given notice of an entity's information practices before any personal information is collected from them. Without notice, a consumer cannot make an informed decision as to whether and to what extent to disclose personal information.

While the scope and content of notice will depend on the entity's substantive information practices, notice of some or all of the following have been recognized as essential to ensuring that consumers are properly informed before divulging personal information:

of the entity collecting the data;

of the uses to which the data will be put;

of any potential recipients of the data;

nature of the data collected and the means by which it is collected if not obvious (passively, by means of electronic monitoring, or actively, by asking the consumer to provide the information);

the provision of the requested data is voluntary or required, and the consequences of a refusal to provide the requested information; and

steps taken by the data collector to ensure the confidentiality, integrity and quality of the data.

Choice/Consent: The second widely-accepted core principle of fair information practice is consumer choice or consent. At its simplest, choice means giving consumers options as to how any personal information collected from them may be used. Specifically, choice relates to secondary uses of information, uses beyond those necessary to complete the contemplated transaction.

In the online environment, choice easily can be exercised by simply clicking a box on the computer screen that indicates a user's decision with respect to the use and/or dissemination of the information being collected. The online environment also presents new possibilities to move beyond the opt-in/opt-out paradigm. For example, consumers could be required to specify their preferences regarding information use before entering a web site, thus effectively eliminating any need for default rules.

Access: Access is the third core principle. It refers to an individual's ability both to access data about him or herself -- *i.e.*, to view the data in an entity's files -- and to contest that data's accuracy and completeness.

Security: The fourth widely accepted principle is that data be accurate and secure.

Enforcement: It is generally agreed that the core principles of privacy protection can only be effective if there is a mechanism in place to enforce them.

EU Proportionality and Transparency: One of the privacy concerns most often expressed by the public are the IoT will be used to secretly track individuals. There is fear the technology will allow collection of personal data without the individual's knowledge or consent. In order to address this privacy concern, the European principles of "proportionality" and "transparency" should be applied to the IoT. "Proportionality" in this context requires a balanced analysis of assessing risk and mitigating risk based upon threat to privacy. If the implementation is "proportionate", then the implementing entity should provide "transparency" thereby ensuring the IoT is not secretly used to collect data.

Reasonable and Adequate Notification: In order to achieve transparency, individuals should receive reasonable and appropriate notification of the type of data collected and how the data will be shared and used. Achieving "reasonable" and "appropriate" notification should vary based upon the type of data collected.

IoT implementation should consider whether the ability to be disabled at some point (e.g. the right to be forgotten)²⁹ or the right to the silence of the chips³⁰. Both these concepts are being reviewed within the context of the ongoing review of the EU Data Directive. The determination to disable should be made by focusing on whether disabling (e.g. a kill tag) is necessary to mitigate real risks to individuals. For example, an RFID tag in an item which an individual will carry

²⁹ Dou, Eva, Internet Privacy and "the right to be forgotten", Reuters March 17 <http://www.reuters.com/article/2011/03/17/us-eu-internet-privacy-idUSTRE72G48Z20110317>

³⁰ 'Right to the silence of the chips' in the new EC Communication 1 July, 2009, EDRI-gram - Number 7.13, 1 July 2009 <http://www.edri.org/edri-gram/number7.13/right-silence-of-the-chips>

with them consistently (e.g. a watch) may provide less risk, if it allows the individual to disable the tag. Conversely, a tag placed in product packaging which an individual will discard quickly; there is likely little need for the disable function.

Apply Existing Data Collection Privacy Requirements and Frameworks to the IoT:

Like other technologies that collect personal data (e.g. behavioral advertising), the focus should be on ensuring only data related to achieving the stated business objective will be collected. Moreover, data collectors should make certain collected data will be protected with the same rigorous privacy standards applied to personal data collected from other sources.

This policy position shifts the focus away from the IoT and turns the focus to the broader issue of ensuring there are rigorous privacy data protection policies in place to protect all individual privacy data, regardless of the source of that data. Typically these broader policy standards apply to how the data is stored and protected on the back-end, such as the database, where the data is stored, the processes used to manage and protect the collected data, and how the data is protected when shared with authorized third parties.

For instance, many press articles have focused on risk scenarios which are unlikely or impossible (e.g. networks of readers which will track the location of individuals). Education can help reduce this fear. The IoT discussion should also be expanded beyond privacy issues to the broader societal benefits the IoT can deliver.

Unintended Consequences

Governmental regulations mandating the type of acceptable IoT technology has the potential to chill or slow future industry innovation. Rather than focus on regulating IoT technology, the focus should be on a comprehensive approach in the EU and US to generate general privacy standards that are robust through the rigorous protection of stored personal data, and controlled use of that data, regardless of the source. Finally, regulations should focus on punishing inappropriate behavior when an individual, company, or agency violates regulations that protect personal data and its use.

Challenges in an IoT world

The application of these four areas of policy raises a series of crucial questions. How will the principles of notice and choice apply? What does transparency mean and what's the right level? The challenges of providing access are especially pronounced if there is not a direct interaction with a particular device. How do we incorporate privacy by design into the initial design and manufacturing phase to consider/alleviate many of the privacy issues that connected devices might present? Can industry self regulation and the FIPPs work for the IoT to form the foundation of global privacy laws and regulations?

Questions To Consider

How will the principles of notice and choice apply?

What does transparency mean?

How do we provide notice appropriate to circumstances to individuals when data is collected that may be associated with that individual?

How do we avoid IoT specific government mandates to ensure continued technological innovation in the marketplace?

Conclusion

We need to move away from catchy slogans like the "silence of the chips" _such thinking leads to many missed opportunities. The ongoing review of the EU Data Directive coupled with proposed legislation in the United States cite to Kerry McCain/Obama admin calling for baseline privacy protection creates a unique transatlantic opportunity to redefine privacy protection and effective enforcement mechanisms. When dealing with issues surrounding privacy, one must assure to take into account both existing regulatory and policy constructs as well as technology solutions, which enable further security and privacy. There are many examples of the benefits of the IoT including: the smarter planet, smart grids, smart transportation, and transforming global transportation to name but a few. Privacy by design, privacy impact assessments, and privacy enhancing technologies should all be considered as a means to promote trust and confidence

in this new medium. These new concepts must be allowed to develop. The focus needs to be on actions that are the most damaging and most likely to occur. Processes need to be developed to assess and mitigate risk to identify things of highest concern e.g. actions that threaten one's most sensitive information and then designing effective enforcement mechanisms.

4. Scope and Impact

The above sections have dramatically demonstrated the importance of the IoT and the increasingly role it will play in social life. In this last section, we look more specifically at the current scope and potential impacts of the IoT. Weber (2010) argues that the increasing ubiquity of the IoT requires new regulatory approaches to ensure privacy and security and asks "for a heterogeneous and differentiated legal framework that adequately takes into account the globality, verticality, ubiquity and technicity of the IoT." More specifically, some starting points come from a recent presentation at the Expert Group on IoT from the European Commission by Rudolf van der Berg (OECD). According to van der Berg, who spoke his personal opinions, there are several issues to consider in the near future:

Competition especially in the mobile wireless market. For example, the role of customers is changing with car companies now managing more devices than there are citizens in some OECD countries. To foster competition it would be good that these car companies can enter the wholesale market independently and buy and sell national and international roaming independently of operators.

Spectrum Policy, the internet of things is here for the long haul. This also means it locks in spectrum use in the long run. IoT devices are not like consumer electronics with an expected operational life of 5 years. IoT is about 5-30 years. Policy makers need to be aware of the long term effects.

Standardization. There are no good IoT standards. We are in a VHS vs Betamax situation with all the short range low energy wireless communication standards. There are also no uniform ways of connecting devices to gateways.

Privacy, IoT together with the cloud is about information. That information is about us, the way we interact with others. This information is stored and processed at different actors and layers than before. If you don't want your mobile phone to track you, you leave it at home. If you don't want your implanted pacemaker to tell where you are, you may have a problem. Your car will communicate the moment you turn it on.

Numbering policy, a much overlooked area but it determines who can get numbers and who can play in the market.

Public/private sector information. With more information and better correlation everyone could become wiser, under what terms is data shared?

To these we can add:

Funding research. Public funding can help streamline research, which is important as many of the application opportunities and technologies remain to be explored.

Governance. Public authorities may wish having a say in the governance of the IoT. It remains however to be demonstrated that additional governance schemes are necessary.

Security. The main concern of end users might be the possible impact of IoT technologies on their health. Existing laws and regulations may be sufficient but it needs to be shown they exist and are adequate.

Education. There is a role for public authorities to educate the businesses, public bodies and citizens about IoT, its constraints and benefits.

Dissemination. Public authorities have the duty to help promoting IoT at large but also more specifically the applications that can potentially bring the bigger benefits. This can be done by sponsoring pilots, events and documentation.

Recycling. It remains to be proven whether the increasing use of tags and sensors deserves a special attention.

Global cooperation. Needless to say, the large majority of IoT applications has and will have a global dimension. Public policies should always consider the big picture before addressing national and regional needs.

These categories can and should be the focus of attention by policy-makers as well as developers themselves. In the section below we call attention to the current developmental approaches to the IoT, using China, the EU, and the U SA as exemplars. We follow this up with a general categorization of these and similar approaches, claiming that more proactive forms of governance and policy-setting are required. We end with some conceptual arguments from the growing field of *infrastructure studies* which provide guidance for a more nuanced attention to the complexities of the IoT policy space.

Development approaches

A quick analysis of the current state of IoT globally shows three approaches aiming to build - more or less- governance reference architectures that offers a framework for decision making, as well as collaborative governing, tax systems, generic infrastructure, legal frameworks and resilience. These are:

(1) An **integrated approach** in China able to steer on broad investments in infrastructure, smart cities, software, applications and services. The 2006 RFID whitepaper was released by a total of 15 Ministries and Commissions, including Ministry of Science and Technology of PRC. Premier Wen Jiabao proclaimed the city of Wuxi as the China's IoT capitol and called for the rapid development of internet of things technologies. Therefore, the IoT can be claimed in the Chinese notion of "Sensing Planet" as "original" as any other vision available. It is able to integrate IoT fully into its technical architecture of the future internet. There are on going sensor projects in Wuxi and the city's mayor proclaimed the 530 Project with his aim to bring 30 IoT entrepreneurs to Wuxi within five years. Start-ups are supported and given free office spaces in Wuxi to promote growth in the region and on IoT. It is interesting to see the interest in China for a bottom-up approach with regard to facilitating discussion at local levels; deliberative democracy. How this could be linked to the Sensing Planet idea is uncertain. Fishkin (2006): "Whether widespread Deliberative Polling would contribute to democratization in China is an open question. ...But it can promote the notions that government can be responsive to public needs and that citizens can voice their views in a context of equality and mutual respect. It could contribute to democratic development over the long term by educating participants and observers in the ways of democratic citizenship and giving them a sense of empowerment."

(2) A **stakeholder approach** in the EU that favors public-private partnerships and vertical investments through four-year programme plans. This organizes internal competition, even between its own flagship projects, while aligning major IoT projects with future internet is not yet a dedicated goal. This approach aims to bring a broad adoption of potentially privacy-invading and business disruptive IoT as a set of applications. These should bring convenience, safety, and cost efficiency to the domains of health, automotive, smart energy grids, the home. In order to do this, the EU has set up risk assessment procedures (Privacy Impact

Assesment for RFID, Internet of Things Impact Assessment for IoT) with a broad and wide variety of stakeholders (the IoT Expert Group).

(3) An **opportunity investment approach** in the US that is driven by short to mid-term return on investment. It is pushed by smart energy, smart cities, and RFID fuelled by Department of Defense and Wal-Mart. Big data, the cloud and the growing synergies of B2B and B2C, through social media networks, lead to a convergence of back-end and real services and applications: location-based services and augmented reality (e.g. Facebook buying Nextstop, smart energy to the home and community applets (LogMeIn buying Pachube), (NFC) handheld device integration (Google buying Motorola). No US wide policy, no stakeholder debate. Large opportunities at local and city level where local decision power is harnessed. There is an appreciable amount of 'buzz' in this area.

The above approaches each have strengths and weaknesses. They each balance important issues of technical stability, security and privacy, with the need to maintain and extend innovative programs. However, it is not clear to what extent the three approaches listed above currently incorporate and make use of new peer-to-peer developments. To what extent do the approaches all fail to take the citizen - the end user - into account as a new systemic force? Key research questions center around the changing roles and power relations between informed citizens and institutions of governance. Just as novel socio-technical development such as crowd-sourcing and commons-based peer production (Benkler, 2006) have had dramatic effects on previous expert communities and their products (e.g. encyclopedias, software, media production,) so too such practices and communities will have a dramatic effect on the development of the IoT.

In addition, how do these approaches address the growing importance of open data, particularly by SMEs, and by regional and municipal governments – some of the most important customers for the IoT? The Open Data movement that aims to open up data that have been collected, acquired and stored by public funds and means is growing. "Take data that you and I have already paid a government agency to collect, and post it online in a way that computer programmers can easily use. Then wait a few months. Voilà! The private sector gets busy, creating Web sites and smartphone apps that reformat the information in ways that are helpful to consumers, workers and companies." (Thaler, 2011)

In the past eighteen years of the browser we have seen a trend towards collaboration and sharing. We have gone from text and images towards building new operating systems, open hardware (OpenBTS, OpenBSC, Oswash) and even an open Global Village Construction Set (50 tools for building post-scarcity, resilient communities). It is hard to find one city that is not involved in open government projects or open data schemes. So far these open projects have required little resources but we are now reaching a milestone where this technology will be used to transform future cities. IBM's City Forward is a philanthropic donation of services and technology urging citizens to "use data and visualizations to come up with new ideas and share them with others." Eduardo Paes, mayor of Rio de Janeiro, has asked IBM to build a "Single City Operations Center" that would allow him to "monitor, command, & forecast critical events across the city."³¹ Guru Banavar of IBM's Smarter Cities group says: "This is a very special thing for IBM, because we're seen as a trusted adviser by the mayor – not a vendor, not even a partner." Addressing the need for open data by many of the potential customers of IoT systems is an important priority.

Finally, one of the main questions in IOT research in the next decade involves the exploration of citizenship in a digitally-enabled world. How can we help existing institutions and power nodes to transform into a networked form of a variety of heterogeneous forms of organisation that need mediation? Might we not be able to facilitate citizens with the individual and community tools that are necessary to perform the functions of current institutions and democratic processes: slow down, mediate, negotiate, educate, take a longterm perspective...?³² Mireille Hildebrandt, using the term Ambient Intelligence; calls for developing an Ambient Law along these lines:

"In the case of Ambient Intelligence (AmI) we may need to develop an Ambient Law that is embodied in the algorithms and human machine

³¹ Arkenberg, Chris 2011 Rio de Janeiro partners with IBM to build a smarter city, <http://www.psfk.com/2010/12/rio-de-janeiro-partners-with-ibm-to-build-a-smarter-city.html>

³² in: Nold, C. van Kranenburg R. (2011) The internet of people for a post-oil world. New York: Architectural League of New York.

interfaces that support AmI and for this we will have to break through our paralysis, ready to become literate in terms of a new script.”³³

Moving Beyond A Reactive Approach To Governance

From the previous chapters we can break down IoT – albeit in a very simplistic manner - into 4 layers:

A **value chain** where all objects can be tracked, logged and traced.

A **service layer** will be build on this, currently mostly by mobile operators who will be offering filtering layer deals to customers just as they do now with sms/gsm.

On top of this layer – and currently interwoven in it through the public private partnerships - we find the **smart city layer**.

The ultimate limit and scope of the **Sensing Planet** notion is to capture natural processes by globally distributed sensor grids to have counterpart in the cloud.

These layers do not neatly align, yet they offer a boardroom visualization.

In each and every one of these layers key issues are emerging or have emerged. In the value chain the debate is about the possibility of a global value chain at all, who should facilitate and provide governance, what technical protocols could form this ecology. Tentative solutions have also emerged, such as federated EPC Global ONS trials in France, see chapter 2. Privacy and security are the main issue in the applications and services domain. The Privacy Impact Assesment (PIA, below) is a unique combination of industry led and policy backed instrument that was negotiated by a wide variety of stakeholders in the RFID expert group. The smart city concept is the actualization of the need of different layers of governing (EU, national, and regional) to find funding for infrastructural work with sensor based infrastructure. Maintaining control and governance in a fuzzy, dynamic environment is the key driver behind the Sensing Planet idea and

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in : A Vision of Ambient Law by MIREILLE HILDEBRANDT. See also: Hildebrandt, M (2006a) 'From Data to Knowledge: The Challenges of a Crucial Technology' DuD—Datenschutz und Datensicherheit.

FP7 Security. This has led to a broader diffusion of the Open Data movement in contrast to the control notion that builds closed systems.

At this time, it is possible to take one of two differing approaches to governance and investments, a reactive approach or a proactive one. *The reactive approach* takes a defensive approach and sees Internet of Things as a manageable technological series of developments. Addressing the issues from the current economic and socio-cultural realities it aims to manage the 'extra' connectivity that IOT brings, assuming that this 'extra' will not change the basic elements of the economic, socio-cultural and political realities. Against such an approach Santucci (2011) argues that "the main problem today, and especially tomorrow, is not only to determine if and how we'll preserve our right to privacy but what will be the place of human beings in a society in which the largest population will be the one made of smart objects enabled by ICT with the attributes of "subjects".

Alternatively, *a proactive approach* confronts Internet of Things as an existing and rapidly innovating set of devices, protocols, and systems and works back from that situation to the current political, economic and socio-cultural realities. Based on this idea, it becomes obvious that individuals as well as social groups need to be educated into the realities involved in sharing decision-making with autonomous M2M operations. Possible results include the failures of existing business types as well as the development of new business opportunities. Current democratic processes could be severely disrupted and/or new approaches to political participation may be engendered. Here, the main question is whether or not the current groups studying global IoT Governance are able to act *proactively* to shape the scope and import of IoT.³⁴

In this final section, we explore the cornerstones for a proactive approach seeing these as involving attention to *privacy, standards, educational tools, and inclusive designs* for IoT services for the home, transportation and energy, and the city. We will then description relevant work on the nature of infrastructure that provides

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The Global Standards Initiative on Internet of Things (IoT-GSI) promotes a unified approach in ITU-T for development of technical standards (Recommendations) enabling the Internet of Things on a global scale. ITU-T Recommendations developed under the IoT-GSI by the various ITU-T Questions - in collaboration with other standards developing organizations (SDOs) – will enable worldwide service providers to offer the wide range of services expected by this technology. GSI also aims to act as an umbrella for IoT standards development worldwide.

some guidance towards a useful analytic model of IoT and end with an example of such an analysis.

The Privacy Impact Assessment Case

As we look into ways to address the Internet of Things from a political stand, we do not need to go too much back in time to find a truly disruptive positive policy approach to technology developments and most importantly, to the resulting user applications. One example of that is the recent European policy approach to Radio Frequency Identification.

In 2006, Information Society Commissioner Vivian Reding announced the Commission's intention to scrutinize Radio Frequency Identification, identify its benefits and the societal and economic challenges it would pose. The Commission opened a very broad and exhaustive debate on different policy aspects such as security, health, privacy, standardisation, environmental etc. The debate was highly publicized in the press, and all stakeholders had the opportunity to give their opinion through a public consultation and a series of workshops. At this stage, the policy positions were extremely reactive ones.

As a result of the intense debate, the European Commission developed its structured policy thinking around the subject, already outlining some sense of political direction on the matter through a Commission's Communication. It should be noted that one of the most effective guiding points of the Communication was the support for deepening the dialogue with all relevant stakeholders, best expressed through the creation of an RFID experts group, including representatives from governments, data protection authorities, companies, standard organizations consumer group and privacy advocates. The focus on stakeholder dialogue was a key to turn a highly reactive debate into a proactive/ constructive one. Stakeholder dialogue will be a constant through the years to follow and even today, as the RFID Experts Group evolved into a renovated Internet of Things Experts Group last year.

Looking back at those days of intensive exchange of opinions, awareness raising and learning from each other's concerns and proposals, one can see why the Commission services in charge of the dossier decided not to sanction the results of the RFID dialogue into a one single binding piece of legislation but came close to self-regulatory approaches by adopting a non binding Recommendation in 2009.

The Recommendation on Privacy and Security Aspects of RFID was addressed at Member states, like previous recommendations, but included very precise instructions to industry and other stakeholders.

The RFID Industry Privacy Impact Assessment Framework is the first result of that Commission's Recommendation. It is a co-regulatory instrument supported by the European Commission and the National Data Protection Authorities gathered at the so called Article 29 Working Party. It is the first instrument in the EU that includes a harm based approach, in other words it does not focus on the technology itself but on the use of the technology and the "likely" privacy risks (as opposed to the "possible" risks) it entails in the context of the application of usage at stake; it is sufficiently flexible to be future proof and relies on making privacy principles enshrined in the current EU privacy regime effective.

Privacy and Trust

Professor Mireille Hildebrandt of Radboud University, Nijmegen in the Netherlands works on profiling technologies on human identity and legal subjectivity. This involves issues of liability, causality, data protection, privacy, non-discrimination and intellectual property. Her article, A Vision of Ambient Law addressed many legal issues relevant to the IoT. Her work on the hidden complexity of smart environments raised a number of issues, notably concerning fundamental human rights that are constitutive for the rule of law, such as privacy, non-discrimination and due process. For instance, fundamental questions she raised include: "which rights and options does one have if a smart environment implicitly takes a decision that affects my life, based on statistical profiles; which options does one have to protect personal data and/or to control its usage by smart environments; how can one possibly contest such decisions?"

At Lulea University of Technology, professor Avri Doria (2010) addresses the relationship between the objects and the people associated with those objects. She asked: what can be known? What should be known? What should be private? Doria also addressed security questioning what are the limits to scope of access, encryption, key registration, verification, and authentication?

Weber (2011) also explored issues of privacy and the IoT. He discussed the technological components to IoT privacy, such as encryption, ID management and PETs. Moreover, he looked at user's rights, public awareness, disclosure

statements and user advocacy. From a legal perspective, Weber analyzes user consent, collection limitation, use limitation, openness, and accountability.

Moving away from issues of trust and privacy, Auto-ID Lab, a research group in the field of networked RFID and emerging sensing technologies, has published "What is the Internet of Things? - An Economic Perspective". Here Fleisch explored the factors and measures that might determine possible earning and value to companies and organizations of IoT applications. It also examined related benefits for businesses and users. Such drivers include proximity triggers, automatic sensor triggers, automatic product security, and user feedback. The above arguments demonstrate that the creation of new IoT standards turn on more than just technical questions but need to address social issues as well.

Standards

The primary standards bodies or agencies who aim to manage standards in IoT are varied both locally and internationally. Internationally, it is the International Telecommunication Union (ITU), International Organization for Standardization (ISO), International Electrotechnical Commission (IEC), GS1/EPC Global, the Institute of Electrical and Electronics Engineers (IEEE). In Europe it is the European Telecommunications Standards Institute (ETSI) and European Committee for Electrotechnical Standardization (CEN/CENELEC). In China it is the Ministry of Industry and Information Technology, the China Communications Standards Association and the China Electronics Standardization Institute (CESI). In the US, the standards body is the American National Standards Institute (ANSI). As an exception, it does not presently seek to implement standards on the IoT (Chinese Communication Network, 2010).

There is a delicate balance between producing standards at an early phase of development, or letting the developers and users determine organically which protocols are best serving the dynamic IoT and applications. On the one hand, standards can produce more quickly a format to promulgate the spread of IoT technology. Particularly, it is China who is calling for standards to be defined in the IoT, claiming that standardisation is urgent. In an article by c114.net in Dec. 2010, Wen Ku, director of the Technology Division of the Ministry of Industry and Information technology, as well as Zhu Gaofeng, chairman of China Communications Standards Association advocated for the study of and advancement of standards in IoT.

Along these lines of advocating for standards, there is the view that competing standards may paralyze markets as users and consumers will wait for a dominant technology to emerge. In a report by the University of Aachen, delayed standards may negatively impact their competitiveness, as some producers may get locked into old technology. Authors Jakobs, Wagner, and Reimers assert that to avoid such a situation, co-ordination between standards bodies is necessary and that such co-ordination exists and should be implemented. They state that various formal contracts exist, including the World Standards Cooperation (WSC) that governs the relations between the international standards bodies International Organization for Standardization (ISO), Electrotechnical Commission (IEC), and International Telecommunication Union (ITU). Similarly, the Vienna Agreement [ISO, 2001] provided the basis for the co-ordination of the work done within European Committee for Electrotechnical Standardization (CEN/CENELEC) and ISO. Lastly, the authors assert that EPC Global is an “Approved Referenced Specifications Originator Organization” of the Technical Committee 1 (JTC1), of Electrical and Electronics Engineers (IEEE) and ISO have signed an “ISO/IEEE Partnership Standards Development Organization” (PSDO) agreement (Jakobs, 2011). Therefore, as one will note there are many permutations of standards in IoT. The lack of homogeneity among standards bodies is a noteworthy and ponderous point in and of itself.

Another claim to early adoption of standards is the issue of interoperability. Ican, while it does not deal with matters of standardization, it does promote interoperability for the development of the IoT. A European standards body, ETSI states that, “incomplete, unclear standards with poorly specified options can contribute to the biggest single cause of non-interoperability, namely that the unfortunate implementer is forced to make potentially non-interoperable design.” There is further the notion of differing interoperability, for example: technical interoperability, syntactical or syntax interoperability, semantic interoperability and organizational interoperability (van der Veer, 2008).

A panel group discussion at the June 2011 Forum Europe's conference on the internet of things led to consensus, particularly by the ITU and Europe's ETSI agreeing that the responsibility of standards should not be with a single organization, but rather be a community based standards movement. ITU and

ETSI stated, among several others, that they are open to working with the industry and other standards bodies in order to develop standardization in IoT.

A contrary approach to rigid standards development and regulation is to let technology develop naturally, through trial and error and user uptake. Proponents of less early adoption of standards prefer to let the community decide the mechanisms that work best, allowing for a flexible evolution. Proponents of looser standards for the IoT suggest that without enough time to allow for the dominant standard to emerge, artificial standards can be adopted prematurely.

Pasi Hurri, of Finish company BaseN Corporation, and Usman Haque of Pachube, has stated that they preferred to let technology evolve before implementing overly stringent standards. Hurri brings to light the history of the internet protocol established by ISO called ISO-IP that was the officially recognized internet protocol. Contrarily, TCIP developed by the Arpanet and the US Department of Defense, naturally emerged as the dominant protocol for web interaction. ISO-IP, as a standard that was adopted artificially early still exists, but only serves a role in optical equipment, such as under-water sea cables, and is incompatible with TCIP.

These two protocols were declared to be the standard to be adopted and developed from, yet, where in fact not favoured in the long run. Patrick Wetterwald of Cisco has further stated that not only does IoT need to be built on open standards, but it needs to be open source, inter-operable and certifiable.

Skeptics of premature adoption, such as those above, remind us to think about who is asking for the standards? There is the topic of accountability of standards bodies, additionally. Weber suggests that standards need to be introduced that hold governing bodies accountable, information should be made more readily available and beneficiaries of accountability must be able to impose some sort of sanction on the accountable in case of non-compliance. Improving accountability by creating such framework also supports the betterment of security in the Internet of Things (Weber, 2011).

Educational tools: NFC and the Privacy Coach.

A key issue for a functioning IoT is adoption by relevant users and social groups. However, many individuals remain concerned by the privacy issues associated

with IoT systems. Here, the arguments made by Cecile Crutzen (2006) in *Invisibility and the Meaning of Ambient Intelligence* are explicitly pertinent: "The Information Society can only be reliable if it is capable to construct, connect and nourish these rooms where doubting the promises of, ambient intelligence (AmL), is a habit. Being aware of the redesign of borders is a necessary act for creating diversity in interaction rooms — where people and society can choose how the invisible and visible can interact, where they can change their status, where the invisibility could be deconstructed."

"We cannot innovate in a bubble if citizens are not coming along for the journey", Neelie Kroes, Vice-President of the European Commission responsible for the Digital Agenda, stated in her opening for the High-level Internet of Things conference "As the IoT matures into the connected society", Budapest, 16th May 2011:

"Whether it is Smart Cities, eHealth and Assisted Living, Intelligent Manufacturing, Smart Logistics and Transport, or Smart Metering, 21st century machines are now sensing, anticipating, and responding to our needs; and we can control them remotely.... We cannot have a policy or create the impression that the Internet of Things would create an Orwellian world. Our goal, and our commitment, should be to create a vision that focuses on providing real value for people."

Privacy Enhancing Technologies (PET) and privacy by design are thus proactive tools. The Privacy Coach, produced by a small Dutch consortium of RFID experts, is an application running on a mobile phone that supports customers in making privacy decisions when confronted with RFID tags (Broeninjk and others, 2011). It functions as a mediator between customer privacy preferences (Fischer-Hübner, 2011) and corporate privacy policies, trying to find a match between the two, and informing the user of the outcome.

However, more work needs to be done to educating citizens as to the problems and the benefits of IoT. A potential starting point is current media education initiatives at the secondary and post-secondary levels (if not before) and innovative curriculum that blends technical work and social insight. (Ratto & Hoeckema, 2009; Ratto, 2011)

Inclusives designs for IoT Services

The need for a proactive and inclusive approach to the IoT is clear. Three examples are given below of its importance, each of which emphasizes different needs and issues.

1.1 Home

The house will be the key focus for eHealth and the aging European population and become an 'actor' trying "to maximise the comfort of each of its inhabitants by learning the individual preference profiles." (Internet of Things 2020 Roadmap) The biggest challenge is that of balancing security with convenience for such uses and at-risk users. The number of general- and specific-purpose devices connected to the internet, either directly or through a gateway ³⁵ is growing exponentially. One can only wonder how to adequately share and sort through the devices and their data reliably and conveniently, yet securely. This is even more of a challenge when considering the countless respective individual and corporate needs. This situation requires a flexible and Open Source combination of hardware, software and protocols to be designed and implemented.

1.2 Transportation

Rudolf van der Berg (see above) proposes that car companies will enter the wholesale market independently and buy and sell national and international roaming independently of operators. Social and mobile technologies will transform the car ownership experience. (Toyota 2011, Pressrelease). Again,

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For example, the Herma box will bridge home-based data providers to roaming users and global consumers, like smart-grid platforms. It will be a gateway: it will act like a firewall when necessary and a gateway by default. It aims to provide different APIs depending on the consumer, be it a home appliance or a corporate environment, including ISPs or energy and media suppliers (probably 'one' service layer in the near future). The box developed in this project can also be a base for an IoT label, which could in turn be extended to other Things. With this working it would provide a gateway to a more industrial, yet open, hackable and eco-friendly home environment, as a potential plug to other dedicated services and open hardware modular items: washing machines, coffee machines, power monitoring tools to share locally and globally. For technical details see the website / wiki: <http://herma.duekin.com/>

security will be a key focus. Another driver is electrified vehicles (EV) for application in the urban environment; research should focus on the development of smart infrastructures, and innovative solutions which will permit full EV integration in the urban road systems while facilitating evolution in customer acceptance." (2011 FP7 Call GC.SST.2012.1-2. Smart infrastructures and innovative services for electric vehicles in the urban grid and road environment.) In September 2011 the Commission adopted the first measure towards the mandatory introduction of eCall: a Recommendation to EU Member States to ensure Mobile Network Operators support eCall. It will dial 112 for you automatically when the sensors detect a serious accident, sending a so-called "Minimum Set of Data" with key information about the incident. The (SMART 2010/0064, study report) on automated driving, cooperative driving, and autonomous driving concludes that "a more concrete standardization program will certainly help the industry, the regulators, and the road infrastructure owners to take the right decisions in due time and avoid thereby undesired costs introduced by uncertainties in their business models."

1.3 City

The Nikkei Business Publications estimates that smart city market will be a cumulative total of 3.1 trillion Euro for the next 20 years (Smart Connected Communities, 2011) According to Intelligent Community Forum, more than 500 cities globally have been introduced with "smart" technologies. For example, the following cities being created are: Neapolis, Cyprus; Songdo and Incheon South Korea; King Abdullah Economic City, Saudi Arabia; GIFT, Lavasa, and Nano City, India; Wuxi Huishan and Meixi, China; Masdar, UAE; Living PlanIT Valley, Portugal; and Skolkovo, Russia.

However, it is not clear how cities will adopt new IoT infrastructures. As Bruce Katz argues in Smart Cities USA: "Instead of cashing in on what could be a \$1.2 trillion industry, our patchwork collection of local, city, and state governments fight over who should pay to update our infrastructure. This needs to stop. The United States would seem tailor made for this market transformation. One of the most urbanized countries in the world, cities and metropolitan areas house over 83% of the population and generate 90% of national GDP. US companies (and the US military) have been innovative leaders in the invention of technologies critical

to making cities smart. Despite these natural advantages, the US lags rather than leads the move towards smart cities technologies at scale when supported by strong public policies at the national scale ... The most important barrier; however, to US leadership may be *institutional fragmentation*.. An excess of municipal governments (and the general absence of metropolitan governments) means that there is no “one stop shop” for the application of innovative technologies in American cities and metropolitan areas.”

How to Analyze IoT - Some Conceptual Guidance

How might policy-makers, technology developers, and interested citizens parse the IOT in a way that allows them to address its complexity? While technical values such as functionality and ease-of-use can guide initial development, social values more associated with political action and citizen rights may be more appropriate for this longer term. We can imagine that values such as transparency, interoperability and openness will be important, just as they have been for the development of the Internet itself.

In this regard, there is particular danger from various forms of 'lock-in', whether at the vendor or customer³⁶ level. History has shown that lock-ins can reduce³⁷ innovation in computing and recent scholars have highlighted the issue³⁸. Governments have demonstrated a willingness to intervene when such lock-in's threaten social values such as freedom of expression and economic values such as a competitive marketplace.³⁸ Creating such interventions becomes both more important and more difficult with the IoT.

³⁶ Greenstein, S. M. (1995). Lock-in and the costs of switching mainframe computer vendors in the US federal government in the 1970s. *IEEE Annals of the History of Computing*, 17(3), 58-66. doi:10.1109/85.397061

³⁷ Borenstein, N., & Blake, J. (2011). Cloud Computing Standards: Where's the Beef? *IEEE Internet Computing*, 15(3), 74-78. doi:10.1109/MIC.2011.58

³⁸ Clemons, E. K., Barnett, S., Gokal, R., Hu, K., & Madhani, N. (2010). Self-Regulating Public Servant, Profitable Internet Innovator, or Rapacious Monopoly: Assessing Google, Thinking about the Possibility of Regulation. 2010 43rd Hawaii International Conference on System Sciences (HICSS) (pp. 1-10). Presented at the 2010 43rd Hawaii International Conference on System Sciences (HICSS), IEEE. doi:10.1109/HICSS.2010.332

Some assistance can be gained by consulting a new and growing field of social research. *Infrastructure Studies*, a cross-disciplinary research area includes researchers from Information, Sociology, Political Science, and Computer Science. Together these researcher's goal is to develop case studies on infrastructure as well as ³⁹ novel methods for unpacking its importance for social life. Three insights from this field are most relevant here:

Infrastructure is relative: one person's helper is another's hindrance.

Infrastructure is socio-technical and made up of technical apparatus, institutions and social groups, as well as individual practices.

There is both a tendency for infrastructures to become invisible as well as a need to reveal them, given their importance.

First, it is important to recognize that infrastructures are not experienced the same by all individuals and groups. This relativity was first noted by Star and Ruhleder ⁴⁰ who described the ways in which infrastructures are learned by individuals as they become members of particular communities. For members of these groups, infrastructures become naturalized, for newcomers and strangers they are encountered at best as unfamiliar objects to be learned, and at worst as barriers to activity.

Second, infrastructure is best considered as a hybrid of social practices, institutions and communities, as well as technical objects. Here, ⁴¹ infrastructure scholars leverage work from Science and Technology Studies to unpack the

³⁹ For more readings in this area, a good starting point is Bowker, G., Baker, K., Milerand, F., Ribes, D., Hunsunger, J., Allen, M., & Klasrup, L. (2009). *Towards Information Infrastructure Studies: Ways of Knowing in a Networked Environment*. Springer Verlag..

⁴⁰ Star, S. L., and Ruhleder, K. 1996. Steps Toward an Ecology of Infrastructure: Design and Access for Large Information Spaces. *Information Systems Research*, 7, 111-133.

⁴¹ Here, the work of scholars such as Susan Leigh Star, Geoffrey Bowker, Steve Shapin, Simon Schaeffer, Bruno Latour, Trevor Pinch, and many others in particularly relevant. For an introduction to some of this work, see Sismondo, S. (2009). *An Introduction to Science and Technology Studies* (2nd ed.). Wiley-Blackwell.

complexly interwoven nature of infrastructures in daily lives. Any attempt to understand and govern the IoT as an infrastructure should start from a similar understanding.

And finally, infrastructure has a tendency to fade into the background except when it is not functioning. Given its relative nature and links to particular social memberships, invisible infrastructures can thus be a source for inequality by encouraging some to use them while discouraging others. To combat this, Bowker defines interventions he called 'infrastructural inversions'⁴² which seek to expose and reveal the inner workings of their socio-technical systems. This invisibility is not just an automatic part of infrastructure. Instead, it is often designed in and seen as an important and necessary characteristic. Here, the rhetoric of 'seamless infrastructure' is particularly strong with few alternatives being proposed from within the field of design or computer science.⁴³ The dangers of seamlessness for ubiquitous computing infrastructures have been described in more detail previously by Ratto.⁴⁴

There is great value in considering the IoT from the perspective of infrastructure. It is obviously experienced 'relatively' with some users finding it easy or even invisibly assisting them, while others will have more difficulty. The IOT is also socio- technical rather than 'purely' a technical apparatus. And finally, the IoT is both necessarily and problematically invisible. In fact, if we consider the rhetoric associated with the trajectory from Ubiquitous Computing to Pervasive Computing to Ambient Intelligence, to the Internet of Things, it appears to involve the movement of computational resources more and more into the background, with less and less human involvement in the processes of

⁴² Bowker, Geoffrey C. 1994. *Science on the run: Information management and industrial geophysics at Schlumberger, 1920-1940*. Cambridge, MA: MIT Press.

⁴³ An exception to this is Chalmers and Galani who have described a practice calls 'seamful design.' Galani, A., & Chalmers. (2004). *Seamful interweaving: heterogeneity in the theory and design of interactive systems*, (August), 243-252.

⁴⁴ Ratto, M. (2007) "The Ethics of Seamlessness: Resources and Future Directions," *International Review of Information Ethics*. Vol. 8 - Ethical Challenges of Ubiquitous Computing.

computational decision-making, and environmental sensing and control. One way to consider the IoT is as a paradigm for computing in which humans have left the scene entirely. As Nold and Von Kranenburg have argued, this is an incorrect vision.⁴⁵ Overcoming and replacing this vision with one that emphasizes open standards, shared development, and inclusive designs will encourage innovation while maintaining the social values which have informed the development of the Internet requires attention.

Speed, scope and shape

The speed with which the paradigm of connecting communicating objects has taken over the full range of connectivity protocol (ipv6), hardware (from cheap sensors to smart phones, ipads, tablets that are full blown computers), software (either proprietary in the cloud or collaborative open source), applications (ranging from location based services that link up to social networks to your car linked up to a particular brand network) and services (from carsharing with rfid cards (Buzzcar), to blinds texting you or your service layer that they are out of battery power (Designer) is determined by the collaborative power of the internet. The first browser, Mosaic, went online in 1993. For most people the browser is the Internet. In its only 18 year history it has managed to change or disrupt nearly all managerial processes effecting business, media, eduactions, politics, in short the scope of human life. Lone entrepreneurs and 'sudden' voices that would have been filtered out before the internet can now publish, be heard and gain influence. One of the best examples of this is Google. Once, only eleven years ago, it was a series of patches on a search engine protocol, a recent estimation shows it is now worth \$163.2 billion (November 2010).

IoT is comprised of a number of technological protocols that aim to make up to 'glue' of connecting things to other things and to databases, that are currently being shaped and discussed such as ipv6 for IP, and EPC global, OID, federated ONS for RFID. A recent startup in the white space range, Neul, points to potential disruptive ways of using spectrum. As such it is not sure what its relationship is to Future Internet, if it is the future Internet, or a layer of services and

⁴⁵ Christian Nold and Rob van Kranenburg (2011) The Internet of People for a Post-Oil World, Situated Technologies Pamphlets 8: Spring 2011.

applications, or a set of communication protocols specifying how objects can be enhanced to become smart objects. In its current phase its shape appears to be all.

The scope of IoT is informed by the crisis of representation that some have labeled a crisis of post postmodernity leading to a renewed interest in the 'real' and the growing importance of the notion of 'data'. In the case of IoT the promise seems to be that it generates a new ratio between data and noise: it brings raw data to the enduser, it allows the enduser to generate new data . The third operation builds new correlational tools that find data where only noise was thought to be before, either because it could not be massively scaled, the sensors were not susceptible enough, or the data mining algorithms not suitably refined.

Policy, industry and democratic institutions have to face the consequences of growing groups of media and sensor literate individuals able to organize themselves through the internet and through data gained from cheap sensors in the IoT. Balancing security and resilience with end user programming, convenience and innovation is a challenge to them all. Key research questions center around the changing roles and power relations between informed citizens and institutions build during the book age. Which new notions of quality and formats of data, information and knowledge will inform decision making, governing and leadership?

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A Note On The Authors

Rob van Kranenburg wrote *The Internet of Things. A critique of ambient technology and the all-seeing network of RFID*, (Foreword by Sean Dodson), Network Notebooks 02, Institute of Network Cultures, in 2007. Although the arguments lined out are very critical he was asked to join the Expert Group of the European Commission. He moderated the business and policy focused Internet of Things Forum Brussels three years in a row. He founded Council, a thinktank for the Internet of Things (www.theinternetofthings.eu) in 2009, which has currently 80 members ranging from artists and designers, to Creative Directors at Philips and academics such as Liam Bannon, Matt Ratto, Ben Schouten, Francesca Bria, Karmen Franinovic, and Florian Michahelles. His latest project is involving the Dutch Belastingdienst, from the Ministry of Finances. They are interested in IoT as it enables more or even full traceability and transparency that could lead to new and different tax 'apps'. A second reason for them to be interested in IoT is that they see the need to accommodate the current call for openness and accountability by citizens. The UK has set up <http://wheredoesmymoneygo.org/> "trying to make government finances much easier to explore and understand - so you can see where every pound of your taxes gets spent." The Dutch pilots, apps and scenarios for ministerial and senior management levels that Council will be involved in are considering participatory budgeting (allowing you to spend some amount of your taxes locally) and a rethinking of VAT. He is involved in a Paris based startup called CKAB. He is a member of the Expert Group on Internet of Things (EG IoT) for the European Commission.

Erin Anzelmo earned her master's degree in International Law (LL.M.) with research focus on the Internet and international law. Erin has worked with a think-tank, the Global Trust Council (GTC), in Malmo, Sweden on eIdentification, consulting on human rights in the digital realm. Erin served as assistant to the Secretariat of the European eSkills Association (EeSA) in Brussels, as well as volunteered with ISOC to form the ISOC Rwanda Chapter. She is published in The Brussels Journal of International Relations on Cyberspace and International Law.

Despite being tempted by other disciplines, **Alex Bassi** decided to explore the esoteric world of computer science, mainly because of his tension between creativity and mathematical rigour. He enjoyed his stay in Milan, where he attended its world famous University, and became passionate of artificial

intelligence, soft computing and software engineering. After serving his duty in the army, as many of us, he lent his abilities to the private sector, and joined Amadeus in 1997, to become -against his will- an expert of Unisys OS 2200 assembler. He then managed to unchain his spirit again and joined the University of Tennessee in summer 2000, where he was involved in the seminal work and development of the Internet Backplane Protocol. After surviving "Nax-vul" for 18 months, he managed to get back to Europe, and in particular to Lyon, where he had a position as Research Visitor at the Ecole Normale Supérieure. For two years, he developed the relationship between the novel storage concepts and active networking. He then worked for RIPE NCC, working on project regarding the whois database such as the AfriNIC creation, and after one year of rainy A'dam in November 2004 he moved to the sunny south of France, to integrate the Hitachi Sophia Antipolis Labs. There he got involved in various projects, regarding Grid and Cloud (with particular regards to data aspects), Autonomic Communications and RFID. In 2007 he became chair of the then RFID (now Internet of Things) Working Group of the EU Technological Platform EPoSS, and from 2010 he started his own company, Alessandro Bassi Consulting, acting as a Technical Coordinator for the Internet of Things Architecture (IoT-A) FP7 IP project for Hitachi. He is a member of the Expert Group on Internet of Things (EG IoT) for the European Commission.

Dan Caprio brings over 25 years of experience on legal and policy issues involving the convergence of internet, telecommunications, and technology. He has substantial knowledge and experience in the areas of privacy, cyber security, information security and the Internet of Things, a term used when everyday objects are connected to the Internet. Mr. Caprio works with clients to define and capitalize on public policy strategies in the United States and Europe. From 2004 to 2006, Mr. Caprio served as Chief Privacy Officer and Deputy Assistant Secretary for Technology Policy for the U.S. Department of Commerce (DoC) where he advised the Secretary of Commerce and the White House on technology policy and privacy protection. While at the DoC, he oversaw activities related to the development and implementation of federal privacy laws, policies, and practices. He served as Chairman of the DoC RFID working group and Co-Chairman of the Federal RFID interagency working group. In 2007, Mr. Caprio was appointed by the Secretary of the Department of Homeland Security to serve on the Data Privacy and Integrity Advisory Committee. In 2010, Mr. Caprio was appointed as a transatlantic subject matter expert for the European Commission's

Internet of Things formal expert group. Prior to his tenure at the DoC, Mr. Caprio served as Chief of Staff to a Commissioner at the Federal Trade Commission. In 2002, he was appointed to represent the United States in revising the OECD guidelines on information systems and networks. Dan holds an active security clearance for classified matters. He is a member of the Expert Group on Internet of Things (EG IoT) for the European Commission.

Sean Dodson is a senior lecturer in journalism at Leeds Metropolitan University. He is also a journalist and writer and has been covering the social uses of technology for over 10 years. He has also worked as an assistant producer at the Guardian and a researcher for the Sunday Times, as well as contributing to a wide range of titles including Wired, Design Week, UK Press Gazette, The South China Morning Post and the Melbourne Age.

Matt Ratto is Assistant Professor, Faculty of Information University of Toronto. Ratto received his PhD from the University of California, San Diego in 2003, writing his dissertation on the social organization of the Linux development community. Following this, he completed a 2 year post-doc at the Netherlands Institute for Scientific Information (NIWI) and in 2005 helped create the Virtual Knowledge Studio for the Humanities and Social Sciences in Amsterdam (VKS-KNAW). In 2005, he was awarded a Netherlands Science Foundation (NWO) grant to study the use of computer simulation and modeling technologies in Archaeology and in 2007 was given a 1 year fellowship in the HUMlab, an innovative digital humanities laboratory located at the University of Umea, Sweden. He moved to the University of Toronto in 2008. His current research focuses on how hands-on productive work – making – can supplement and extend critical reflection on the relations between digital technologies and society. This work builds upon the new possibilities offered by open source software and hardware, as well as the developing technologies of 3D printing and rapid prototyping. These technologies and the social collectives that create, use, and share them provide the context for exploring the relationship between ‘critical making’ and ‘critical thinking.’ Ratto is currently director of the Toronto ThingTank Lab (formerly DDiMIT), a private-public-academic consortium interested in investigating, exploring, and building capacity around new developments in tangible interfaces, smart objects, and digital infrastructures. Departing from the traditional model of the hackerspace, ThingTank is an “digital economy trading zone”, a virtual and physical space where Ontario companies,

academic institutions, and community organizations can leverage their joint knowledge and skills in order to support each other in doing novel research, creating innovative products and services, and fostering creative and engaging work in the Internet of Things.