The Internet of Things

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Introduction

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

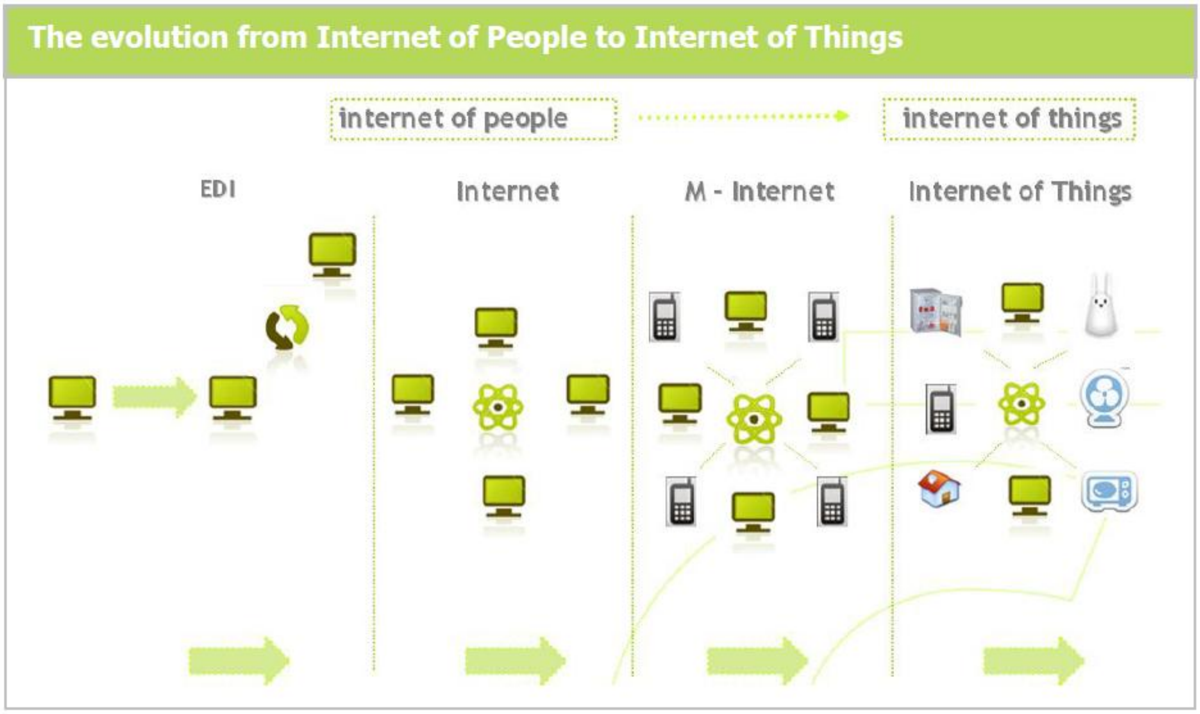
- Kevin Ashton, inventor of the term 'Internet of Things' (Ashton, 2009)

"Yesterday's computers filled rooms – so will tomorrow's".

- Friedemann Mattern (Mattern, 2009)

In the Internet of Things, basically everything can be connected to the Internet. Every 'Thing' becomes a small computer that communicates with other Things. Communication between computers has evolved significantly over time. It started with electronic data interchange (EDI), then computers communicated over the Internet, then mobile phones got Internet access, and in the future, Things will have Internet access. See figure 1.

Figure 1: The evolution of communication between computers (Casaleggio Associati, 2011: 4)



This paper will explore the concept of the Internet of Things. It does so from a general business perspective (as opposed to a purely technological perspective).

Theoretical framework

The theoretical framework discusses the Internet of Things, the potential uses, the technology, the regulatory environment and the future of the Internet of Things.

The Internet of Things

Already in the early 1990s, Mark Weiser (1993: 75) described a vision where "each person is continually interacting with hundreds of nearby wirelessly interconnected computers". In another article Weiser (1991) wrote: "the most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it". He called this vision 'ubiquitous computing'. Basically, this is the core idea of 'the Internet of Things', a term coined by Ashton in 1999 (Ashton, 2009). There are several definitions of the Internet of Things. This paper uses the following definition of the Internet of Things:

"*A world where physical objects are seamlessly integrated into the information network, and where the physical objects can become active participants in business processes. Services are available to interact with these 'smart objects' over the Internet, query their state and any information associated with them, taking into account security and privacy issues*" (Haller *et al.*, 2009: 2).

If there was a vision statement for the Internet of Things, it would be: "a world where 'things' can automatically communicate to computers and each other, providing services for the benefit of human kind" (CASAGRAS, 2009: 2).

A 'Thing' in the Internet of Things can be everything, like the garage, camera, security mechanisms like locks, heating, ventilation, air-conditioning, appliances like the fridge or the oven, shutters, lightning, the curtains, watering the garden (International Telecommunication Union, 2005: 3). In the Internet of things "real world objects have an individual digital presence" (Siorpaes *et al.*, 2006: 1).

The Internet of Things revolution has already started, with the widespread use of Smartphones with Internet access. It is actually expected that in 2013, more than one billion people worldwide will have a Smartphone (Middleton, 2010). The tablet revolution, led by the iPad, can also be seen as another device that brings the world one step closer towards the Internet of things. Table 1 shows the road towards a widespread Internet of Things.

Table 1: the evolution of the Internet of Things (Casaleggio Associati, 2011: 6)

	Stage 1	**Stage 2**	**Stage 3**	**Stage 4**	**Stage 5**
Name	The world is the index	Take the world online	Take control of the world	Let the things talk to each other	Let things become intelligent
Example	All the monuments of the world are described in detail on the Internet	The packages that we send are tracked on the Web and we know where they are	Lost or stolen objects (e.g. car keys) can tell us where they are	Plants can water themselves when they are thirsty	The alarm can ring earlier in case of traffic or bad weather

It should be noted that there are already some stage 5 products available on the market. However, the challenge of the Internet of Things is to get many products in stage 5 available for many people. The Internet of Things is not only benefiting rich countries; The International Telecommunication Union, 2005: 10) states “the enabling technologies of the Internet of things have much to offer developing countries in their goals for improving the quality of life”.

The Internet of Things means that “virtually every physical thing in this world can also become a computer that is connected to the Internet. To be more accurate, things do not turn into computers, but they can feature tiny computers. When they do so, they are often called smart things, because they can act smarter than things that have not been tagged” (Fleisch, 2010: 3). ‘Smart’ objects can make decisions themselves and are expected to play a critical role in the Internet of Things (Mattern & Floerkemeier, 2010). In other words, “computing power will be embedded in devices that are not regarded as computers” (The Hammersmith Group (2009b: 4).

Naughton (2011) observes that the Internet of Things is driven by 2 trends: (1) that sensors and actuators are increasingly being embedded in physical objects – from phones to pacemakers – which are linked via the Internet, (2) that there are now enough Internet addresses to assign a unique one to every object on the planet.

A report by the International Telecommunication Union (2005: 2) says the Internet of things brings a new dimension to the world of information and communication technologies; while Internet connectivity already was possible anytime, anyplace, for anyone, the Internet of things enables connectivity for anything. Fleisch (2010: 5) mentions that the Internet of Things adds another data dimension, by allowing things to generate data automatically.

Casaleggio Associati (2011: 4-5) states that the Internet of Things makes it possible for Things to get information about their position and to interact with other Things. The Cluster of European Research Projects on the Internet of Things (CERP-IoT) puts it this way: “things become context aware and they can sense, communicate, interact, exchange data, information and knowledge” (CERP-IoT, 2009: 8). The Internet of things gives rise to the ‘Web of Things’, which is “the idea of accessing surrounding devices through Web applications” (Duquennoy *et al.*, 2009: 1). The Commission of the European Communities (2009: 2) states that these new connections can be divided into restricted areas (Intranet of Things) and publicly accessible connections (Internet of Things).

The Internet of Things fulfills an unfulfilled need. Kindberg *et al.* (2002: 374) note that people’s everyday activities mostly concern physical objects, but these objects are not linked to computers or the Internet. They then argue that “users can benefit from greater connection between the physical and the virtual worlds, and that the Web is the best technology for building that connection”. Haller (2009: 2) says” the role of the Internet of Things is to bridge the gap between the physical world and its representation in information systems”.

Mattern (2009) states that the Internet evolved from a network of computers, to a network of documents, to a network of people & services, and is evolving towards a network of Things. Others see an evolution from the Internet, to mobile Internet, towards the Internet of Things (Dodson, 2008). The Internet is set to become “fully pervasive, interactive and intelligent” (International Telecommunication Union, 2005: 13).

Raunio (2010: 32) mentions that "a sign that the Internet of Things is a technology on the threshold of a great breakthrough is that the European Commission has begun to involve itself at EU level and has formulated an action plan for the Internet of Things". But Europe isn't the only region where the government is working on the Internet of Things. America is also investing heavily in underlying technologies of the Internet of Things and the Chinese Premier said the Internet of Things "will have a rosy prospect" (MacManus, 2010). In 2008, the Internet of Things got international recognition of its importance, when it was actually put on the list of 'Best inventions of 2008' by Time Magazine (www.time.com). This emphasizes that the Internet of Things is a technological innovation that is on the threshold of a great breakthrough (Raunio, 2010: 9).

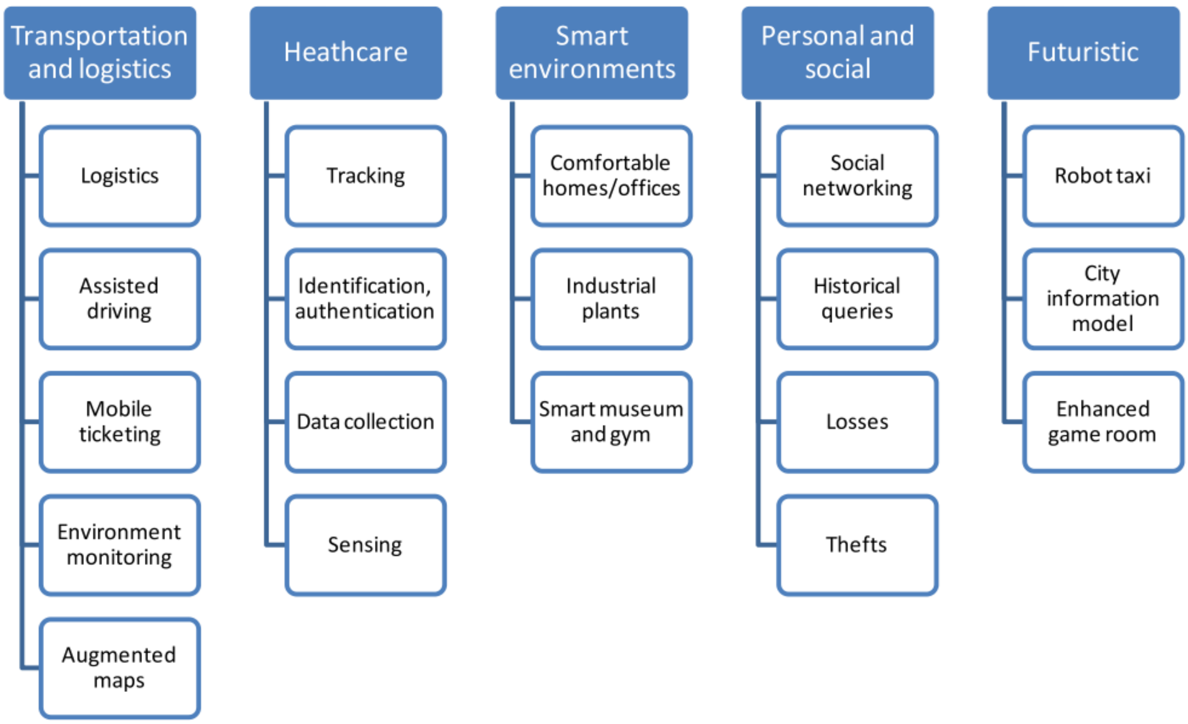
Although the Internet of Things is attractive, there is no consensus yet on how to realize it (Kortuem *et al.*, 2010).

Potential uses

The Internet of Things will have a big impact on several aspects of daily life for people around the world, and on the behavior of people (Atzori *et al.*, 2010: 2787). There are almost an unlimited amount of potential uses, and only some of them are mentioned in this paper. Several authors have tried to categorize the potential uses of the Internet of Things, resulting in various categorizations.

Atzori *et al.* (2010: 2793) categorize the application domains for the Internet of Things in: (1) the transportation and logistics domain, (2) the healthcare domain, (3) the Smart environment (home, office, plant) domain, and (4) the personal and social domain. Each of these domains has several practical applications. See figure 2.

Figure 2: Application domains of the Internet of Things (Atzori *et al.*, 2010: 2794)



The Commission of the European Communities (2009: 2) explains how the Internet of Things is expected to contribute to society: "health monitoring systems will help meet the challenges of an ageing society; connected trees will help fight deforestation; connected cars will help reduce traffic congestion and improve their recyclability, thus reducing their carbon footprint". Other authors mention more potential uses of the Internet of Things (International Telecommunication Union, 2005: 12; Casaleggio Associati, 2011: 3; Mattern, 2009: 4; 22; 14):

- Smart packaged food that communicates with the microwave the time needed to it warm up;
- Credit cards that only work in the hands of its owner;
- Finding lost or misplaced personal items;
- Cars that give automatic warnings if a part of the car needs to be fixed;
- Clothes with weather-adjusting features;
- Wireless transmission of driver's license and passport information at borders, so that cars don't have to stop for the passport control at the border;
- Alarms clocks that go off early if there is traffic;
- Running shoes which communicate time, speed and distance so that runners can compete in real time with others on the other side of the world;
- Medicine containers that tell family members if you forget to take the medicine;
- Plants communicate to the sprinkler system when it's time for them to be watered.

This last example actually already exists in some form. Called Botanicalls, it basically is a sensor that you can put in your plant at home, and the sensor monitors when the plant needs water. The sensor is connected to the Internet and sends the plant-owner Tweets on Twitter like "water me please", you didn't water me enough" or "thank you for watering me" (botanicalls.com).

The Hammersmith Group (2009) gives some more examples of what cars might be able to do in the context of the Internet of Things: communicate real-time data about driving conditions, give driving recommendations based on this data, record vehicle performance data, indicate where parking spots are currently available, automatically avoid collisions and traffic jams, automatically send data about other dangerous drivers on the road to the police, and synchronize the location of the car with a Smartphone so people will never forget the location of their car anymore. For example, if all cars and public parking spaces are equipped with a sensor, the car can automatically find an available parking spot.

Atzori *et al.*, (2010: 2787) mentions that "from the perspective of business users, the most apparent consequences will be equally visible in fields such as, automation and industrial manufacturing, logistics, business/process management, intelligent transportation of people and goods".

McKinsey (2010) states that the Internet of Things creates new business models, improves business processes and reduces costs and risks. They have come up with their own categorization of the Internet of Things, which categorizes applications in 6 types of emerging applications, which can be further divided into 2 categories See table 2.

Table 2: Categorization of applications for the Internet of Things (McKinsey, 2010)

Category	Application	Examples
Information & analysis	Tracking behavior: monitoring the behavior of persons, things, or data through space and time	- Presence-based advertising - Inventory and supply chain monitoring and management
	Enhanced situational awareness: achieving real-time awareness of the physical environment	- Sniper detection using direction of sound to locate shooters - Security personnel that can use sensors to spot unauthorized individuals entering restricted areas
	Sensor-driven decision analytics: assisting human decision making through deep analysis and data visualization	- Oil field site planning with 3D visualization and simulation - Continuous monitoring of chronic diseases to help doctors determine best treatments
Automation & control	Process optimization: automated control of closed (self-contained) systems	- Continuous, precise adjustments in manufacturing lines
	Optimized resource consumption: control of consumption to optimize resource use across networks	- Smart meters and energy grids that match loads and generation capacity in order to lower costs - Data-center management to optimize energy, storage and processor utilization
	Complex autonomous systems: automated control in open environments with great uncertainty	- Collision avoidance systems to sense objects and automatically apply brake - Cleanup of hazardous materials through the use of swarms of robots

Technology

The Internet of things is real. The International Telecommunication Union (2005: 2) states: “the Internet of Things is neither science fiction nor industry hype, but is based on solid technological advances and visions of network ubiquity that are zealously being realized”.

The Internet of Things shouldn’t be seen as an extension of the current Internet, but as a “number of new independent systems that operate with their own infrastructures (and partly rely on Internet infrastructures)” (The Commission of the European Communities, 2009: 2). When it comes to the application level, Internet of Things applications never work stand-alone, but always use Internet-based services as well (Fleisch, 2010: 6-7). Table 3 shows the differences between the Internet and the Internet of Things.

Table 3: the main differences between the Internet and the Internet of Things (Fleisch, 2010)

Internet	**Internet of Things**
Flashy hardware	Invisible hardware
Billions of network nodes	Trillions of network nodes
Cable (which often requires fast Internet access, like 100MBit/s)	RFID (which doesn't require fast speeds. 100kBit/s is normal)
User-centric	Machine-centric
Focus on communication	Focus on sensing the physical world
Several existing protocols, like HTTP and HTTPS	No standards. Requires new global protocols and standards

The Internet of Things represents the future of computing and communications, and its development depends on technical innovation in a number of important areas, from wireless sensors to nanotechnology (International Telecommunication Union, 2005: 3). As Atzori *et al.* (2010: 2787) says: "any serious contribution to the advance of the Internet of Things must necessarily be the result of synergetic activities conducted in different fields of knowledge, such as telecommunications, informatics, electronics and social science". These fields will work together to introduce a new mass technology. However, the Hammersmith Group (2010: 2) says that technology should be a means to an end rather than a goal in and of itself.

The Commission of the European Communities (2009: 5) mentions that "things become connected by getting assigned an identifier and a means to be connected to other objects or to the network". Things can be identified by ID numbers, names or location addresses (CERP-IoT, 2009: 6). The Internet of Things is a "world-wide network of interconnected objects uniquely addressable, based on standard communication protocols" (EPoSS, 2008: 6).

It is said that RFID (radio frequency identification) technology is a prerequisite for the Internet of Things (EPoSS, 2008: 5; Atzori *et al.*, 2010: 2790). RFID performs the 2 basic functions of the Internet of Things: identification and communication (Mattern & Floerkemeier, 2010: 9). In the context of the Internet of Things, RFID means that every Thing gets a small RFID tag, which can be identified by other computers. For example, if every parking spot got a RFID tag, a car can read the RFID tags to see where parking spots are available. The International Telecommunication Union, 2005: 7) states that "RFID is the most mature of the enabling technologies with established standardization protocols and commercial applications reaching the wider market". RFID microchip tags can be so small that they are invisible: Hitachi has developed a RFID tag with the dimensions 0,4mm x 0,4mm x 0,15 mm (Atzori *et al.*, 2010: 2790). In addition, it is a cost-effective system of item identification (International Telecommunication Union, 2005: 3) and the cost of RFID has decreased significantly over the past few years. However, Atzori *et al.* (2010: 2803) warns that since RFID is a wireless technology, all RFID communication should be protected with encryption.

Mattern & Floerkemeier (2010: 11) state that some of the Things in the Internet of Things need to be able to communicate with the Internet. In other words, they need an IP address, and use the Internet Protocol (IP) for communication with other connected devices. They mention that – due to the large potential number of connected Things in the future – Things should make use of IPv6 with 128-bit addresses. IPv6 addresses are 128 bit in length, compared to 32 bits in IPv4. This means that with

IPv6, 2^{128} or $3,4 \times 10^{38}$ IP addresses are available, which should be enough for all objects to become connected in the Internet of Things (Atzori *et al.*, 2010: 2799). However, the adoption of IPv6 is going quite slow, and the number of IPv4 addresses is almost running out. Raunio (2010: 13) states that the development of the Internet of Things may actually contribute to the rapid introduction of IPv6. IP is already the standard for all data communication and will be at the core of the Internet of Things (Raunio, 2010: 12). IPv6 will make all Things identifiable and addressable (EPoSS, 2008: 5). The Hammersmith Group (2009b: 2) says that “by attaching IP addresses to physical objects, people will be able to remotely communicate with or control actual devices through a web-based interface”. In addition, as Smartphones and laptops move to the 4G network, other Things – that don’t need full speed Internet connections – can make use of the 3G network (Tofel, 2010).

With all these new devices, Internet connections will “multiply and create an entirely new dynamic network of networks – an Internet of things” (International Telecommunication Union, 2005: 2).

Regulation

The Commission of the European Communities (2009: 8) states that Internet of Things systems will be “designed, managed and used by multiple stakeholders driven by different business models and various interests”. It is “borderless by nature”, and thus requires international cooperation on architecture, standards and governance.

A joint publication by the European Consumer Voice in Standardization (ANEC) and the European Consumers’ Organization (BEUC) states that the Internet of Things raises new challenges, like “new threats to consumers’ fundamental rights, of which the protection of privacy and personal data, to security but also regarding uncertainties on the impact on human health such as the level of exposure of people to multiple sources of electromagnetic fields (EMF)” (ANEC/BEUC, 2008: 2).

The International Telecommunication Union, 2005: 8) mentions that one of the most difficult challenges in the widespread adoption of the Internet of things are concerns about protection of data and privacy, because the ‘Things’ of the Internet of Things will know people’s habits, preferences and can track movements. They state (2005: 9) that therefore the “principles of informed consent, data confidentiality and security must be safeguarded. Moreover, protecting privacy must not be limited to technical solutions, but encompass regulatory, market-based and socio-ethical considerations”. Similarly, EPoSS (2008: 23) says: “when moving towards the Internet of Things it is mandatory that policy keeps up with technology so that citizens gain confidence in the new technology and will accept to live in the Internet of Things”.

Weber (2010) argues that the Internet of Things requires a new legal regulatory framework that must be established by an international legislator. He states that this legislation must cover “the right to information, provisions prohibiting or restricting the use of mechanisms of the Internet of Things, rules on IT-security legislation, provisions supporting the use of mechanisms of the internet of Things and the establishment of a task force doing research on the legal challenges of the Internet of Things”. Weber (2010: 24) further mentions the following security and privacy requirements for the Internet of Things: resilience to attacks, data authentication, access control, and client privacy.

ANEC/BEUC (2008: 2) states that “consumers need confidence to fully embrace the Internet of Things in order to enjoy its potential benefits”. This requires international legislation and protection. However, The Economist (2007) says that “for the moment the danger is surely too much regulation, not too little”.

The future

In the future, everything will become mobile, everything can be localized and everything will be connected (Raunio, 2010: 23). Currently there are 2,5 billion devices with Internet access (mainly Smartphones and computers), and this is estimated to rise to 100 billion devices in 5 to 10 years (Casaleggio Associati, 2011: 3). In the long run, this number can increase to 100 trillion devices that are connected to the Internet (Traversat *et al.*, 2003). In general, it is expected that the Internet can expand to a thousand times its current size (Raunio, 2010: 7). This makes the potential impact of the Internet of Things enormous.

McKinsey (2010: 2) states that “the widespread adoption of the Internet of Things will take time, but the time line is advancing thanks to improvements in underlying technologies”. They further state that costs of these technologies are falling due to the pattern of Moore’s Law. Similarly, the Commission of the European Communities (2009: 11) writes that the Internet of Things “is not yet a tangible reality, but rather a prospective vision of a number of technologies that, combined together, could in the coming 5 to 15 years drastically modify the way our societies function”. EPoSS (2008: 5) expects that the Internet of Things will become a reality over the next 20 years.

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