A platform for internet-connected wireless sensor networks

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Abstract

Acknowledgements

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Background

2.1 Previous Work

2.1.1 Defining the Internet of Things

The Internet of Things is a high-level concept which encompasses many ideas and technologies, and this makes it difficult to define absolutely. In this respect it is similar to Cloud Computing. Cloud Computing has come to represent different forms to different stakeholders, whether they are application developers, infrastructure engineers or end users. As the concept matured through research, conferences and industrial uptake, Cloud Computing has become identified by its use-cases and marketing jargon. For instance the industry has come to recognise Infrastructure-as-a-Service (IaaS), Platform-as-a-Service (PaaS) or Software-as-a-Service (SaaS) as characteristics of the Cloud Computing concept (Armbrust et al., 2010). History may repeat itself with the Internet of Things where the definition will be refined as uptake and research improves.

In the mean time we can begin plotting the footprint of IoT. The term 'Internet of Things' captures the essence of the vision well; the vision of a world where everyday, physical objects are gateways to web-based services. These so-called 'smart objects' comprise of sensors to perceive their environment or context, as well as a notion of interconnectivity with other objects or services. Connected objects or services may react to collected data to trigger actions, and these actions may be digital or physical. The Internet of Things could be summarised as data collection, aggregation and reaction in the physical domain.

The boundaries between IoT and other trends help to define its place in computing. For instance the research area of Wireless Sensor Networks (WSN) carries similarities in hardware requirements and challenges. In particular, WSN comprise of connected sensors and actuators (Mottola and Picco, 2011). This differs from IoT because of the scope of connectivity; the closed-loop fashion of WSNs limit their potential to specific use-cases whereas the global context of IoT allows for a wider range of applications. Wireless Sensor Networks can form one layer of an Internet of Things application.

The research area of 'Wearables' also overlaps with the Internet of Things. Wearables are 'smart' devices designed to be worn or embedded within the body and combine sensors and some form of connectivity, typically integrating with a smartphone (Wei, 2014; EVRYTHING, 2014). Consumer Wearables products are already on the shelves, such as Fitbit—a wrist-worn personal health tracker. The Fitbit wristband connects to a smartphone with Bluetooth Low Energy (BLE) and this smartphone then provides global connectivity through its wireless connection. Users can sign-in to a web-based dashboard which will collate and organise personal

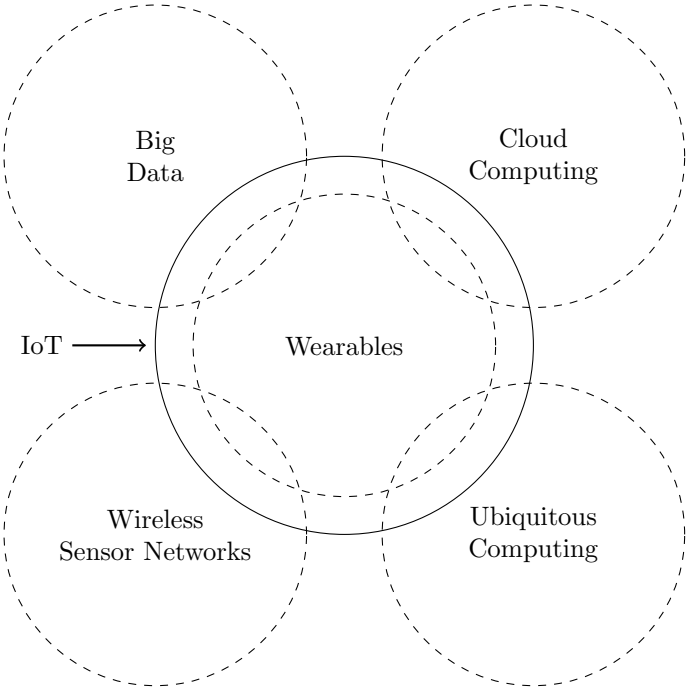

Figure 2.1: Describing the Internet of Things with other trends in computing

data. In this scenario, Wearables are collecting, aggregating and reacting to data in the physical domain. Wearables could therefore be described as a subset of the Internet of Things—they are an application in a specific domain.

Two trends which acknowledge the vastness of information technology are 'Ubiquitous Computing' and 'Big Data'. The Ubiquitous Computing concept describes an environment where users are surrounded by connected technology—technology in our homes, workplaces and recreational activities. Weiser (1999) notes that "specialized elements of hardware and software, connected by wires, radio waves and infrared, will be so ubiquitous that no one will notice their presence" and this is reflective of the vision for Internet of Things. If Ubiquitous Computing describes a physical world saturated with sensors and devices then Big Data describes a *digital* world saturated with huge datasets. These datasets will have different origins and so their structures may differ too; it is the purpose of Big Data to normalise and analyse these on a massive scale. The Internet of Things could be seen as a specific use case for both Ubiquitous Computing and Big Data.

As we have seen, the boundary of the Internet of Things overlaps with other trends in computing. Figure 2.1 exemplifies the extent of which the definition of IoT relies on these related fields. What can be taken away about the definition of the Internet of Things is that it focuses on not just one idea or technology but rather a collection of them.

2.1.2 Opportunities

Why should we develop Internet of Things solutions? Would our society actually benefit from them? These are the questions posed by businesses, consumers, software developers and academics alike. Pilot projects as well as industrial and academic research have shown that there

are wide-reaching opportunities to be grasped. Until recently, these opportunities were achievable only in theoretical, lab-based scenarios but due to the advancements in the supporting technology, they are more achievable for real-world industries.

The technical capabilities of hardware, the readiness of software and all of their associated costs are prominent blockers to the IoT industry. Advancements in the hardware—smaller, more powerful and more efficient microcontrollers—mean that smart objects are technologically more feasible. Large industry players, such as Intel and Samsung, have brought to market the their own IoT hardware platforms—Intel's Edison System on a Chip (SoC) and Samsung's Artik family of boards. Improvements in the mass production of these also reduce financial barriers, making investment more feasible for businesses. The real-world opportunities presented before us can be categorised into two main areas: economic & societal and technical.

Economic and Societal

Irrespective of the industry or domain, the ultimate purpose of Internet of Things is to help people. From the perspective of a service, these applications do and should provide value on an individual basis, however the real value is found with the network effect of interconnected products and services. Both the Internet of Things and societies of people are similar in that their wholes are greater than the sum of their parts.

The European Union (EU) is a prime example of a society which can benefit from the Internet of Things. It is special because it represents the needs and wants of not just one nation but a collection of nations. The European Commission is the governmental body of the EU, which itself recognises the potential in IoT: "One major next step in this development [of the Internet] is to progressively evolve from a network of interconnected computers to a network of interconnected objects, from books to cars, from electrical appliances to food, and thus create an 'Internet of things'." In 2009 the Commission published an action plan for embracing the Internet of Things.

The action plan notes two main areas of opportunity: citizen well-being and economic prosperity. The improved well-being of citizens is achieved through specific and targeted use-cases. For instance internet-connected health monitoring systems could alleviate pressure on medical services for the ageing society, or smart waste management with products which can describe their contents would help to reduce their carbon footprint. The improvement of economic prosperity is achieved through organised and systematic uptake of the Internet of Things. By leading the development of IoT rather than accepting the standards of other nations, the EU can drive development for the benefit of its own industries.

Although there are strong opportunities for individuals and political territories, the best economic opportunites are available to businesses. The Internet of Things has the potential to provide many new income streams to businesses as well as finding other money through efficiency savings. First of all IoT opens up new markets which were previously not feasible nor even considered. These markets may include consumer products such as the previously mentioned Fitbit or novel service solutions such as home security and monitoring. For organisations with complex supply chains or processes, the Internet of Things could help to maximise resources and stock control. This is especially evident in areas such as logistics or public transport where connected devices could help to reduce costs by optimising transportation routes automatically.

Technical

Technical opportunities and advancements are self-perpetuating and really are the driving force behind the Internet of Things. As previously noted, IoT would not be realistically possible without improvements in the underlying technology. As more powerful, efficient and cheaper

hardware boards are delivered and as they become supported by software layers, the possible use-cases of them diversifies too.

Mattern and Floerkemeier (2010) note that the Internet of Things is not the result of a single novel technology but rather several complementary technical developments. These technical developments provide a range of capabilities, or in the eyes of an application stakeholder, technical *opportunities*. The main opportunities presented are: communication and cooperation; addressability; identification; sensing; actuation; localisation; embedded information processing and user interfaces. The authors also note that most applications will need only a subset of these capabilities, but it is better to have the option there.

The value of the Internet of Things is derived from the communication of data—either human-to-machine, machine-to-human or machine-to-machine. This trait makes the capabilities of communication and cooperation, addressability and identification particularly important to its success. Objects with the ability to network between themselves or other Internet services are clearly key. While the Internet will provide the backbone for this, it is the Wireless Personal Area Network technologies which present the opportunities—technologies such as GSM, Wi-Fi, Bluetooth, ZigBee and 6LoWPAN. These technologies in conjunction with other technology layers allow devices to be uniquely identified and addressed from anywhere in the world. With this global interconnectivity, the possibilities really do open up.

The second main characteristic of IoT is the ability to interact with the physical domain. Digital applications will interact with the physical world in two ways: through the monitoring and sensing of physical properties and through the actuation of the physical world in reaction to data. There are a massive variety of sensors available, even to hobby markets, and can measure any imaginable physical property—such temperature (ambient or spot), gas particulates, pressure and distance. Of course sensor hardware is nothing new, however the improved support and reduced cost opens up further opportunities. In a similar vein, actuators such as motors, solenoids or lamps are nothing new but when combined with IoT boards in consumer appliances or industrial applications, anything is possible.

Advancements in technology even provide new opportunities in system architecture. Smart objects will generate a lot of data and given the projected increase in their numbers, the bandwidth available across Internet backbone would become wasted. Since IoT microcontrollers are becoming more powerful, there are opportunities for embedded information processing. Embedded information processing refers to these end devices performing some form of data processing or storage before transmitting their data; for example, an end device might analyse its own data and only transmit if a specific threshold is met, rather than relying on cloud computing-based processing. This is an active area of research called edge computing (or fog computing) and allows for novel methods of data processing.

2.1.3 Challenges

The previously mentioned papers provide solid arguments for investing in the Internet of Things, however this is still an immature area of research with numerous challenges to be addressed. Before IoT will become a mainstream paradigm, the technologies and ecosystem surrounding them must settle and become more mature. In a similar way to opportunities, the challenges can be categorised as Economic & Societal or Technical.

Economic and Societal

If the ultimate purpose of the Internet of Things is to help people then it would be meaningless without them. This is the risk that the industry is carefully attempting to balance; the

social acceptance of IoT products is imperative to their success but consumers and markets could freak out if industries try too much too soon. The European Commission's action plan describes practical challenges which need to be addressed to develop this acceptance: governance, standardisation, security, data privacy and trust.

Many aspects of digital technology is governed by public bodies and the Commission believes that IoT should not be any different. For instance the Internet Assigned Numbers Authority (IANA) is responsible for global IP addressing and the DNS root, two critical components of the Internet. The Commission notes that technology will advance regardless of public intervention due to a normal cycle of innovation and that "simply leaving the development of IoT to the private section... is not a sensible option in view of the deep societal changes that IoT will bring about."

The main areas which may need to be governed are identification, information security and ethical & legal accountability. As we have already established, the value of the Internet of Things is driven by the interconnectivity between devices. Various mechanisms already exist to uniquely address IoT devices however these are not all compatible between applications; if they were, should a public body be responsible for assigning unique identifiers, similar to the Media Access Control (MAC) addresses assigned by the Institute of Electrical and Electronics Engineers (IEEE)? What if an entity illegally or immorally handled sensor or user data—how can they be held accountable and for what? The Internet of Things as a whole will be affected by ineffective governance of these areas—in particular it will suffer from stifled innovation; a mistrust with data and jeopardised system integrity.

Standardisation is a technical consideration but also impacts on the economic potential of IoT. The purpose of a standard is to give different entities and stakeholders a common language to design, build or communicate. The widespread adoption of a standard gives businesses of all sizes the opportunity to develop interoperable solutions. In being interoperable, standards-based solutions will be suitable for a wider market and in turn, this will encourage innovation and improve international competitiveness. If the Internet of Things is to maximise economic impact and to enjoy widespread adoption, there must be accepted practices or formal standards in place.

While governance and standardisation will support IoT, users must be able to accept this new paradigm in their own time. The greatest challenges in this respect are security and data privacy—the protection of privacy and personal data are two fundamental rights in the European Union. The challenge with this, in respect to IoT, is that new methods of collecting and using data will be invented. Does current legislation and safeguards protect the interest of EU citizens adequately? Who will own the data—the user whom it is about or the organisation that captured it? The Commission suggests that in response to this challenge, IoT components should be designed from their inception with a privacy- and security-by-design mindset.

Technical

These challenges can be cross-dependant and many of the points raised about economic & societal challenges are dependant on technical issues being addressed. Since the Internet of Things is not a single novel technology but a collection of cooperating tools, the range of technical challenges is diverse. They vary from the aspects of user experience; device interoperability and discovery; system complexity with regards to scalability, data management & interpretation and code-level complexity as well as hardware challenges covering fault tolerance, power supply and wireless communication.

A good user experience is important for the adoption of IoT products however the underlying technology currently makes some aspects of this difficult. Mattern and Floerkemeier (2010) note that since smart objects will be used sporadically, they "need to establish connections

spontaneously, and organize and configure themselves to suit their particular environment." They coin this requirement 'Arrive and Operate.' A typical home network might use a wireless router, such as the BT HomeHub, to provide wireless local area network (WLAN) coverage. To connect to this network, users are expected to enter some form of Pre-Shared Key (PSK) on the device. While this user experience is fine for computers, laptops and smartphones it is less than ideal for smart objects with little or no user interface. The challenge here is to develop technology which allows consumers to use smart objects with little or no configuration.

IoT innovation is expected to deliver a diverse range products and solutions which makes application interoperability and discovery a challenge. Since manufacturers have the freedom to implement proprietary tools, two systems developed by different manufacturers may not be immediately compatible and this reduces the overall potential of the concept. This issue is further exacerbated by the variety in hardware processing and communication capabilities. The Internet of Things therefore requires common practices and standards to be accepted by the industry (as previously mentioned with regards to economic side-effects). Research efforts have gone some way to address these challenges, such as the IoT 'meta-hub' by Mineraud and Tarkoma (2015).

By all estimates, the Internet of Things will have a larger scope and deployment footprint when compared to the existing Internet of computers which needs to be addressed. The European Commission puts this figure at 50–70 billion devices (on average, 10 per human). Mattern and Floerkemeier (2010) also note that things will be cooperating mainly within a local environment. This means that IoT devices, software and infrastructure must work equally efficiently in both small- and large-scale environments. This complexity is also reflected with the volume of unstructured data being generated; data analysis must be able to scale also, as is being addressed with research around Big Data.

On a lower level, the main challenges present are fault tolerance, power supply and wireless communication. Given how variable IoT environments are (office spaces, homes, public spaces, remote and exposed areas) and how complex the supporting architectures could be, resilience to faults is important. IoT applications should therefore have redundancy across its various technical layers. One main cause of technical faults is the power supply driving any given IoT object. 'Things' are typically mobile and therefore need a self-sufficient power source; the industry is therefore challenged to produce long-lasting batteries while maximising power efficiency in other areas. Existing wireless communication technologies are too bloated and consume too much power, such as GSM, Wi-FI and Bluetooth. To tie these challenges of fault tolerance, power consumption and wireless communication together, IoT applications need lightweight and robust wireless communication standards.

2.1.4 Use Cases

Use-cases are a helpful mechanism for demonstrating the Internet of Things concept. It is a difficult concept to explain because there are many cooperating components and ideas and for this reason, research papers exemplify their arguments with practical examples. Although IoT applications could be developed for virtually any industry there are some areas where its application is more obvious. Some areas which are repeatedly brought up by researchers are smart cities, utilities and logistics. Assuming that the challenges (summarised in Table 2.1) are met, these areas are very achievable.

'Smart Cities' is a vision which convincingly demonstrates many benefits of IoT. The Department for Business Innovation & Skills (2013) describes the main issues facing local authorities, including: piecemeal urban infrastructure, climate change targets, the changing nature of the high street and elderly social care. The economic downturn has also reduced budgets assigned to local authorities by as much as 30% between 2010 and 2013 making cost efficiencies another

Overlapping Research	Opportunities		Challenges		Example Use Cases
	Economic & Societal	**Technical**	**Economic & Societal**	**Technical**	
Cloud Computing	Citizen Well-Being	Communication & Cooperation	Governance	'Arrive and Operate'	Smart Cities
Big Data	Economic Prosperity	Addressability	Standardisation	Interoperability	Waste Management
Ubiquitous Computing	Ageing Society	Identification	Security	Discovery	Smart Traffic Lights
Wireless Sensor Networks	New Markets	Sensing	Data Privacy	Software Complexity	Utilities
Wearables	Business Optimisation	Actuation	Trust	Scalability	Smart Meters
Edge Computing		Localisation		Data Management	Logistics
		Embedded Information Processing		Fault Tolerance	
		User Interfaces		Power Supply	
				Wireless Communication	

Table 2.1: A summary of the current state of the Internet of Things

issue. By developing or retrofitting urban infrastructure with IoT connectivity, local authorities can monitor services in much finer detail. For instance, Bigbelly Solar is a smart waste and recycling system. The Internet-connected waste bins allow local authorities to monitor their status and to schedule collections when they are full. Bonomi et al. (2012) also describe a system of smart, connected traffic lights which can control the traffic flow through a whole city, reducing congestion and improving safety.

IoT in the utilities sector is one use-case which has started to become realised. The British Government is requiring energy companies to install smart meters for their customers and expect most to have a smart meter installed by 2020 (The Department of Energy & Climate Change, 2013). Smart meters monitor domestic energy usage on a per-site or per-socket basis and can give real-time information how much electricity is being used, expressed in pounds and pence. For individual households this has the benefit of enabling homeowners to save money and to reduce emissions. At a national level, smart meters are a step towards reducing energy consumption and meeting climate change goals. Smart thermostats like Nest also allow households to minimise their gas consumption and to reduce heating bills.

Logistics is one area which demonstrates the efficiency savings that an IoT application can make. The European Commission (2007) states that "Freight Transport Logistics focuses on the planning, organisation, management, control and execution of freight transport operations in the supply chain" and notes that it is one of the drivers of European competitiveness. To remain competitive, this industry must continue to improve and streamline infrastructure, fleet management and goods tracking. The Internet of Things could be used to automate good identification and location with inexpensive RFID tags and GPS chips as well as optimise transport routes. This would reduce time spent by workers manually recording goods and it will reduce errors at interchange points. The Commission has coined this the 'Internet for cargo'.

2.2 Existing Platforms

2.3 Sensor Hardware

2.4 Platform Functions

2.5 Case Studies

Chapter 3

Specification

Chapter 4

Design

Chapter 5

Implementation

Chapter 6

Results and Evaluation

Chapter 7

Future Work

Chapter 8

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