INTERNET OF THINGS – WHY NOW?

The Internet of Things (IoT) is the next stage of Internet evolution, enabling objects to sense, communicate, network and produce new information. Early applications are already being used in Transport, Smart Cities, Retail, Logistics, Home Automation and Industrial Control among others. It's not surprising, then, that IoT is starting to attract serious commercial attention. The addressable IoT market in the UK alone was worth £6.4Bn in 2013, and is expected to grow to £30.7Bn[1] by 2019 [1].

The physical world is increasingly connected to information systems as sensors and actuators are incorporated in physical objects – from highways to pacemakers to cattle – via wired and wireless networks. This is the next phase of the evolution of the Internet (see Panel 1), and it enables businesses and consumers to benefit from a wide range of new applications. The IoT will generate massive volumes of data which

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IoT – where do we go from here?

flow to computers for analysis resulting in the collection of much richer information in real time, which can then be used by systems to respond intelligently and automatically with appropriate actions. And it is rapidly moving from the conceptual phase to become a reality.

The IoT has been a recurrent theme among commentators since the term was coined in the late 1990s. It involves radical new views of networked ICT and the relationship between information systems and the physical world. What are driving the changes and what are the implications and opportunities?

The vision of the IoT is that any physical object can be given the ability to measure and respond to its environment, and to communicate with other objects or with computer systems anywhere in the world. This is now becoming technologically feasible and commercially viable.

Our IoT interpretation is also adopted by McKinsey [2] and identifies IoT as: "what emerges when assets themselves become elements of an information system, with the ability to capture, compute, communicate and collaborate around information".

Panel 1. Internet evolution: the next stage

Arpanet back in the 1960s was the first network using the core technology which forms the basis of today's Internet. The following decades have seen a number of stages of Internet evolution.

- The first 'killer app' on Arpanet/the Internet was email and this was followed by other applications such as Usenet discussion groups (a forerunner of today's web-based blogs and discussion forums) and Gopher, an application for distributing, searching, and retrieving documents over the Internet.
- The emergence of WorldWideWeb browsers and servers meant that Gopher failed to achieve significant usage and the web quickly became the dominant application running over the Internet.
- In its early years, the web was primarily an application where information was published by one user and could then be accessed and read by many others in a principally one-to-many model. More recently, the emergence of so-called Web 2.0 has seen a much more participative model where users collaborate to create web content in a many-to-many paradigm. Wikipedia is a prime example of 'crowd-sourced' content and social media systems like Facebook and Twitter are essentially frameworks allowing the community of users to provide all the content themselves.
- The next phase of evolution of Internet applications will be the IoT and the direct connection of non-human 'users' to the Internet (the devices which publish, process and consume Internet data). An interesting aspect of this is the emergence of what are sometimes referred to as cyber-physical systems whereby virtual systems (e.g. sensors and actuators embedded in people, animals or industrial plant) and physical systems directly interact: embedded computers and network monitors and control of physical processes with feedback loops where physical processes affect computations and vice versa.

Why now?

There are both socio-economic and technological drivers for the IoT, leading to expectations of very significant growth over the next 5-10 years.

Falling costs

One of the key factors is the falling cost of key components that will turn things into connected devices. Gartner claims components such as WiFi radios, GPS chips or microcontrollers will fall to less than $1 each in the near term when purchased in volume [3]. It concludes that "the cost of technology to enable the IoT is minimal for many situations and will fall steadily over the foreseeable future".

Societal challenges and resource efficiency

The efficient use of natural resources is becoming increasingly important – with a new emphasis on costs and security of supply, as well as concerns about sustainability. Governments and organisations are motivated to improve the efficiency of their operations and are looking to technological solutions. Urbanisation continues to increase globally and cities are an efficient way to structure societies where natural resources are constrained. However, cities are complex and require effective management if they are to provide high quality environments. The IoT has a central role to play in making more effective use of shared infrastructure. For example, traffic congestion is now estimated to cost the UK economy more than £300Bn between 2013 and 2030 [4]. IoT applications providing intelligent management and improved communication with road users have the potential to reduce congestion significantly.

Information sharing comes of age

A further driver is the fact that people and organisations are getting comfortable with information sharing platforms; 500 million tweets are sent every day and 300 hours of video content is shared to YouTube every minute. Organisations are increasingly using such platforms to interact and share information with their customers. Thus there is increasing public acceptance of the notion of the information sharing platform on which successful use of IoT data will depend. In addition, public administrations and companies are becoming much more aware of the value of effective sharing of information within and between organisations.

Panel 2. Devices everywhere

Worldwide, there are today approximately 1.5 billion PCs and more than 1 billion mobile phones connected to the Internet. The IoT will greatly expand the number of connected devices by facilitating a wide range of uniquely identifiable new devices to be connected. An often-quoted estimate is that there will be 25 billion objects connected by 2020, e.g. [9]. These new networked devices can use the Internet to publish data about their status and to receive data from other devices and human users. The first example application was probably the "Cambridge Coffeepot" as early as 1991; Cambridge University researchers rigged up a web-connected video camera pointed at a coffeepot so that they could get an instant real-time view of coffee availability without the need to make a potentially pointless journey to the coffee room. Since then, the types of sensor and application have expanded rapidly; sensors have been embedded in cattle to monitor health and in running shoes to report runner performance statistics. Other application areas include Smart cities, Environment, Security, Retail, Logistics, Home automation and Industrial Control.

Managing complexity

Increasing scale and complexity of interactions with other stakeholders are challenging many companies today. Managing numerous relationships in a complex, dynamic marketplace is difficult. Similarly, a city comprises a set of complex, interdependent systems which are difficult to coordinate today. The ability to achieve effective visibility and control across systems both internal and external to the organisation, as promised by the IoT, is thus becoming increasingly attractive.

Technological readiness

From a technology point of view, achieving the scale and connectivity envisaged for the IoT depends on the ability to deploy and operate connected sensors, controllers and actuators cheaply and easily (see Panel 2). Network access has rapidly improved, with a range of wired and wireless access technologies now providing wide coverage. As well as cellular and WiFi networks, low power radio technologies well-suited to machine-to-machine communication patterns are becoming available. Flexible computing infrastructures such as Cloud are now well established and offer the ability to deploy applications on-demand in any region of the world.

The IoT market and ecosystem

Big picture

The IoT is still at a relatively early stage so the market structure and size is hard to predict. However, there is growing recognition of its potential impact which indicates its major significance.

Market size

Trying to determine the market size of the IoT is like trying to calculate the market for plastics, circa 1940. At that time, it was difficult to imagine that plastics could be in everything. If you look at information processing in the same way, you begin to see the vast range of objects into which logic, processors, or actuators could be embedded.

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In a recent study [1], IDC has estimated the market size and growth in a range of IoT application areas:

- The global Smart Cities market is expected to grow from $411.31Bn in 2014 to $1,134.84Bn by 2019.
- Retail use cases to integrate all available shopping channels – in-store, online store, mobile apps, mail order – to offer seamless shopping experience for customers and digital signage (i.e. digital screens connected to a network that is constantly mining, analysing and responding to a broad spectrum of real and near-real time data to dynamically tune and change the screens' content) generated revenues of €3Bn and €600M in 2014 alone and are expected to increase at a compound annual growth rate of approximately 30% from now to the year 2018.
- Mobility-related applications such as connected vehicles, asset/fleet management and freight monitoring are also gaining momentum and are projected to represent a significant share of the IoT-solutions and applications market in Western Europe by 2018. IoT solutions applied to connected vehicles, for example, already generate revenues for more than €500M and are expected to be at almost €6Bn in 2018.

The EU and national governments have identified the potential of the IoT to make a significant contribution to economic growth in the medium term and are investing significantly via, for example the Innovate UK and H2020[2] research and development programmes.

IoT applications have a characteristic structure with three major components: 1) collecting data from or delivering messages to devices, 2) enrichment of data to generate information in context, and 3) applications which process information and initiate appropriate actions. These are primary activities in the IoT value chain with common requirements (e.g. secure distribution, digital storage and computational processing) that can be generically supported. Some early IoT applications are being built with their own dedicated infrastructure (for example, the UK smart metering initiative) but there are benefits in common approaches which can deliver economies of scale.

The IoT comprises an ecosystem of various players, as shown in Figure 1. Things (devices and sensors of various types) owned by data providers publish information onto the Internet. This requires connectivity through communication services providers, enabling one or two-way communication with connected devices by operating and integrating a range of appropriate local and wide-area networks.

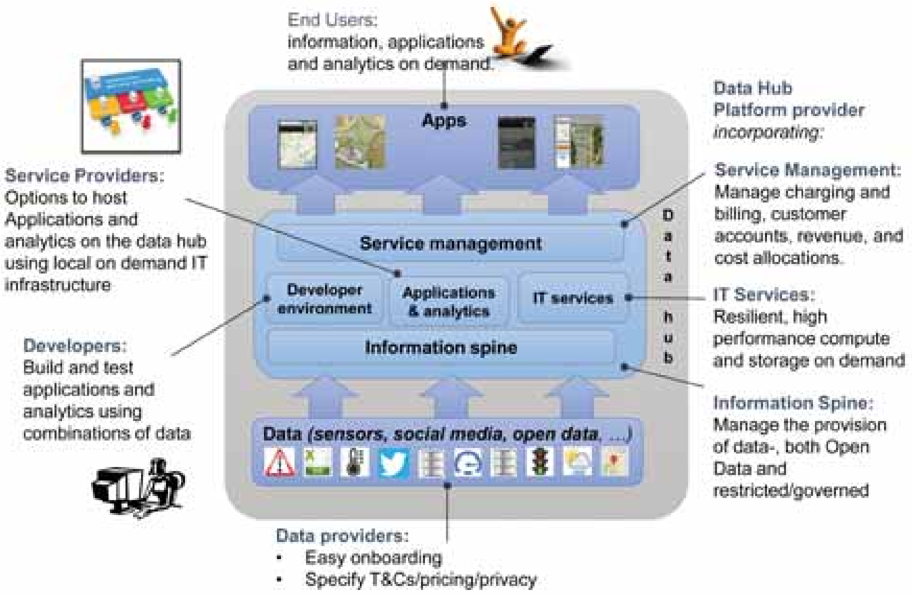

Figure 1: Players in the IoT ecosystem

A data hub provides services for data publication and consumption. These include facilities for data providers to describe and represent their data in standardised formats. App developers (data consumers) are supported with catalogues to search for and discover data sources of interest, and to easily access data in standardised formats to use in applications or in a range of analytical tools. Finally, there is a role for organisations with a data analytics capability, either general purpose or specialised. These organisations federate and analyse data and synthesise new higher value datasets, providing valuable resources to application developers. The ecosystem described here can support a wide range of relationships between stakeholders, with potentially complex value flows. In addition to these roles, service management offers general support functions including service composition, customer care, accounting, tariffing and billing.

The IoT does not represent a fundamentally new technology. It is instead the result of a number of developments in related areas where improvements in capability and reductions in price mean that computational and communications resources can be embedded in essentially any physical device.

Devices

Small, cheap, energy efficient and increasingly capable devices for the IoT are now coming to market, with significant interest from major players. For example, ARM has recently announced its IoT subsystem for Cortex-M processors[3] (of which 11 billion chips have been shipped), with a focus on producing "highly customised chips for smart connected devices" [6]. Such chips can be very small (~1mm^2) and have very low power requirements, meaning they could run off a single battery for several years.

The deployment and management of IoT devices is an important area. There are obvious benefits in deploying sensors, for example, as a general purpose infrastructure to serve the needs of many different customers. However devices present some particular challenges. They will likely be deployed in very large numbers and may be left unattended for several years – in which time new generations of devices will be deployed alongside them.

For service providers to be able to offer the supporting infrastructure for IoT applications, an understanding of how to manage and maintain populations of these devices through their lifecycle needs to be developed. This includes configuration of devices (both initial and in-life updates), addressing, tracking location, assessing the trustworthiness of data and managing the provenance and quality of information provided to customers. This is particularly important for applications supporting critical infrastructure or involving public safety. The use of actuators to control physical systems (e.g. industrial processes, traffic lights) is also challenging in terms of latency, reliability and security from interference.

> **"The IoT is an ecosystem of applications which will be key to a truly IT-enabled world. These applications will help us navigate, and open our eyes to new possibilities in our work and leisure. They will also give us the information we need to use our natural and human resources more efficiently and to increase productivity so that European life is better and more sustainable."**
>
> Neelie Kroes, European Commissioner for Digital Agenda.
> See: http://europa.eu/rapid/press-release_SPEECH-10-279_en.htm

Communications

No single access networking technology will meet all the needs of the IoT. Wireless technologies such as WiFi, Zigbee, 2, 3 and 4G and various low power wide area network offerings are all expected to play a role, but each has different strengths and

Applications include monitoring parking space availability in cities.

limitations. Cellular mobile networks, although most commonly used for connecting devices today are not ideal. While coverage measured with respect to population is very good in many countries, coverage by location is less so.

There are also issues with connectivity inside buildings. Power consumption is high and networks are not designed for very large numbers of connected devices sending short packets of data. As a result, scalability and cost may limit the use of technologies developed for human-centric mobile devices such as phones and tablets. Alternative solutions will offer different trade-offs and provide a range of engineering options for specific deployment scenarios. Efficient networking and application protocols in terms of computational and network resources and energy (battery life) to connect very large numbers of intermittently connected, restricted capability devices are starting to develop. The work of the Internet Engineering Task Force is notable here with a number of working groups addressing the connection of very simple devices to the Internet [7].

Data Hubs

IoT offers an ever-increasing amount of data which is potentially available to exploit in applications. However, there are various technical barriers which need to be addressed if this is to be practical. These include: no easy way for application developers to access data from multiple sources; disparate data format standards; managing high volume and rapidly varying data; 'non-functional' issues such as security, provenance, assurance and verification of data. These barriers are particularly severe for small-to-medium enterprises since typically they do not have the resources to solve these problems as part of developing a focused market offering.

These issues are better addressed by specialist providers of data hubs which can support many applications in a consistent way. We anticipate multiple hub providers, including some specialised for particular types of data and access patterns. Particularly important for realisation of the full benefits of the IoT is that data is able to be discovered and used as widely as possible. Standards have an important role to play here. Standardised catalogues will encourage consistency in the way information providers describe their data and application developers will benefit from uniform interfaces. Hypercat[4] is an initiative to specify a machine-readable catalogue interface against which automated tools can be built.

Ownership of data should not be affected by the decision to make it more widely available via a data hub. As data is transformed, aggregated and enriched, it is important that the rights of data owners are not compromised.

Assessment of the trustworthiness and reliability of information will also be essential. This includes the ability to determine the sources of the underlying data and the processes applied to generate actionable information. These are complex areas involving technology and policy aspects, particularly where personal data is concerned. Human-Data Interaction has recently been proposed as a new topic of study [8]. Main elements of this are legibility – making data and analytics algorithms transparent and comprehensible, agency – giving people the ability to control and correct use of their data and negotiability – concerned with dynamic relationships around data and data processing. These concerns provide a useful way of framing discussions around how data can be effectively shared in a controlled and manageable way.

> "Informa predict a machine-to-machine market value for communications services providers in excess of $65Bn by 2015. Seven out of every ten providers surveyed believe that machine-to-machine will generate 5% or more of revenue within three years."

See: http://www.informatandm.com/wp-content/uploads/2012/04/M2M-Communications.pdf

Applications

Some early commercial uses of IoT technologies can already be seen in areas including security, logistics, retail and environmental management. Attention is also turning to a range of applications with high social impact – such as energy management and healthcare. Clearly, to realise the benefits envisaged in these areas, applications need to be developed which turn the mass of IoT data into actionable information and insight.

Specific example applications include:

- Smart Cities: a wide range of applications including: monitoring of parking space availability in a city, improved waste management via sensors in waste containers, real-time public transport information, smart metering for more efficient use of energy
- Environment: monitoring of soil moisture, vibrations and water levels to detect dangerous patterns in land conditions (used, for example, to warn about risk of floods, landslides and avalanches)
- Security: access control to restricted areas and detection of people in non-authorised areas
- Retail: 'intelligent shopping' retail applications providing point-of-sale advice according to customer habits, preferences, presence of allergic components for them, etc.
- Logistics: quality of shipment environments via monitoring of vibrations, temperature or container/package openings
- Home automation: automatic and remote control of home environment: temperature/humidity control, intruder detection
- Industrial control: such as monitoring of atmospheric conditions in industrial plant, for example ozone levels during the

> "Only 5% of typical large system integration projects are data networks related. The rest is associated with information distribution, IT and applications."

Solace Systems

drying meat process in food factories and monitoring of toxic gas and oxygen levels inside chemical plants to ensure workers' and goods' safety

AUTHORS' CONCLUSIONS

In this article, we have provided an introduction to the Internet of Things. We have examined the set of factors both commercial and technical which mean that the IoT is now reaching critical mass and looked at the current and future size of the IoT market. We then described the key elements of the IoT ecosystem, explaining the interaction between the various actors in that system, including, sensor and data providers, connectivity suppliers, data aggregators, data consumers and end users. We finished by giving some examples of the wide range of application areas for IoT technology. The interested reader is referred to a forthcoming issue of *The Journal* for further details of the various aspects of IoT [9].

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FOOTNOTES

1 This figure includes communications, IT services, software, and hardware complemented additional revenues in by end-user and vertical markets.
2 See https://www.gov.uk/government/organisations/innovate-uk/about and http://ec.europa.eu/programmes/horizon2020/
3 See http://www.arm.com/products/processors/cortex-m/
4 See http://www.hypercat.io/

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