The internet of things: a market landscape

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Executive summary

While the internet of things (IoT) is expected to have a massive impact on business and wider culture, these are still early days. There is no standard definition of the technology as of yet, and protocols and standards are still in development. So what can we expect the IoT landscape to look like, and how will its impact be felt? And is the attention being given by governments, manufacturers, and industry players merited, or is this just a fad?

In this paper we look at the trends leading the growth of the internet of things, its components, and its characteristics. We perceive four stages of development:

- Passive tracking
- More-active interactions
- A more aware landscape of physical objects, devices, and structures
- An autonomous landscape

Each of these represents new opportunities for innovation and enablement. As we speak, we can see players align around where they see the benefits being felt. We examine the scale of the different opportunities and early examples of use cases. We also look at potential inhibitors to adoption and potential challenges, notably around security, privacy, and system failure.

Introduction: the internet of things is everywhere

What if everything you could see, from your coffee mug to your light fitting to a milk carton in the fridge, was connected in some way? What if the door or window could report on whether it was open or the heater's thermostat could be set from your smartphone?

Even as we ask such questions, a future in which physical objects of all kinds and sizes can be connected draws ever closer. Internet-connected objects, devices, and other "things" are proliferating in every domain:

- Farmers' gates can be fitted with SIM cards to monitor whether they have been left open or allow farmers to close them remotely. Cows are being equipped with pay-as-you-go devices, which can send SMS texts when they are in heat.

- Beer barrels now have radio tags so that they can be tracked from brewery to bar and back. Indeed, few supply chains exist today without some kind of automated product tracking. Many major supermarkets now offer bar-code readers to self-scanning shoppers, for example.

- Startups such as Supermechanical and Electric Imp are creating monitoring devices that can be connected to light bulbs or other electrical devices, garage doors, or windows or simply left in the basement to check for water leaks.

- "Things" don't necessarily have to be small: Buses, trains, and cars can be fit with monitoring devices so they can provide accurate information to both control rooms and customers.

The term "internet of things" (IoT) has been adopted to capture this rapidly growing phenomenon. A farmer's gate is a thing, just as a suspension bridge is a thing. Both can broadcast information about their state; both can be signalled to take action in one form or another.

The technology world is becoming increasingly excited, as illustrated by China's creation in August 2011 of a 5 billion yuan (about $800 million USD) special fund to support what it terms the "internet of things industry." All the same, these remain early days: Standards are lacking, the market is highly immature, and a great number of unknowns still exist. In August 2012 EU Commissioner Neelie Kroes launched a consultation to feed into the creation of a regulatory framework.

Trends driving the internet of things

The internet of things is not a single technology trend. Rather, it is a way of thinking about how the physical world at large and the objects, devices, and structures within it are becoming increasingly interconnected. The concepts and enablers are not particularly new:

- **The M2M sensor legacy.** Manufacturing, engineering, utilities, and production environments have been developing sensors and remote monitoring tools for many decades, in a field known as machine-to-machine (M2M) communications, monitoring, and control. Protocols such as supervisory control and data acquisition (SCADA) and Message Queue Telemetry Transport (MQTT) have emerged over the years to enable increasingly complex monitoring and management of anything from air-conditioning units to power stations.

- **Retail and the art of supply.** The retail and logistics sectors have been driving the use of tracking mechanisms for the assets they manage. Passive and active radio frequency ID (RFID) emerged in the early 1970s as one of the first recognized ways of connecting physical objects with the virtual world, used in applications from supply chain management to in-store security systems. Indeed, it was RFID expert Kevin Ashton who first captured the term “internet of things” in 1999.

- **The ever-expanding internet.** The internet needs no introduction. From its inception as an open platform for connecting defense computer systems together, it has become the communications foundation for a globally accessible network. The latest incarnation of the Internet Protocol (IP) V6, with an address space of 3.4×10^{38} unique addresses, was driven by the need to connect an ever-increasing number of compute devices.

- **Broadening (mobile) broadband.** The arrival of asynchronous digital subscriber line (ADSL) broadband communications has enabled households across the globe to gain a high-speed connection to the internet using existing telephone lines. Even as options expand with fibre-to-home, metro Wi-Fi, and 4G mobile, low-power wireless standards such as Bluetooth and ZigBee enable just about everything to be connected together.

- **The cloud and big data.** Things create data — in very large quantities — that needs to be sifted, processed, and acted upon in some way. It is here that cloud computing, big data, and associated models come into play, making possible the vast amount of backend processing and analytics required to deal with these things on a global scale.

- **Loosely coupled software.** The distributed, loosely coupled, transactional approaches now favored in software design provide a suitable architecture within which things can exist and communicate autonomously alongside internet-based services. Service orientation, event-driven architecture, RESTful interfaces, global namespaces, and stateless communications ease the friction among things and the software that monitors them.

We have seen a number of other groundbreaking technologies, and even whole markets, develop around the above. For example, pervasive or wearable computing and smart grids are also based on the ideas of internet-enabled devices that can communicate remotely.

However, the lines between all such disciplines are blurring. The internet of things is most profoundly about the convergence between physical and virtual, between manufacturer and consumer, and between tiny hardware components and large-scale, cloud-based software to create possibilities we have never seen before. The statistics speak for themselves:

- Some 31 billion internet-connected devices will exist by 2020, according to Intel.
- A family of four will move from having 10 connected devices in 2012 to 25 in 2017 to 50 in 2022.
- Mobile subscriptions will exceed the number of people in the world by early 2014.

Historically, the main hurdle has been cost. Meanwhile Moore's law has continued to play out. We only have to look at computers such as the fully functional Raspberry Pi, which packs as many MIPs as a minicomputer of a few decades ago, to see how today's electronic components, controllers, and sensors have dropped below a threshold of generally accepted affordability.

Characteristics of a thing

Before we look at the impact this is having, let's ask the question, What is a "thing" anyway?

At the heart of the internet of things lies the ability of said things to interconnect and interact. Things can be varying degrees of smart; depending on the need, the ability of a thing to respond to an "are you there" request can be sufficient.

We define "things" in terms of identity, interactivity, shadowing, sensitivity, and autonomy.

Identity

For things to be manageable, they need to be identifiable either in terms of type or as a unique entity. For example it may be enough for a retailer to know (from a bar code) that a shipment of tomatoes is in transit between Montpelier and Nice. Or the retailer may require that the specific shipment, the one that was canned three days before at a certain production plant, is now en route.

Identification by type or by instance is fundamental to the internet of things. In general, identifiers are numerical. For example, retail product indices allocate bar code numbers, books have ISBNs, and so on. Individual items can also be allocated by a number. For example, RFID tags can store Electronic Product Codes as a 96-bit data string. IP addresses or hard-coded numbers (e.g., in firmware) can also be used to identify things.

Interactivity

Technological advances have made it possible to connect a wide variety of things and devices. However, it is not essential for things to be connected to a network or monitoring device at all times. Passive things such as RFID-tagged books or DVDs need only be able to report their presence from time to time, such as when leaving a store.

Meanwhile active things, which have greater processing capability, can be connected all the time or may make a connection only when they need to exchange information (or, conversely, may only exchange information when a connection is available). Much of what takes place on the thing itself depends on what happens elsewhere, as we see in shadowing, below.

Shadowing

The notion of shadowing acknowledges that a virtual instance of a thing can exist in the ether. In practical terms, this means a software program is running somewhere that knows everything it can about the physical item and can act on its behalf. So even a physically dumb object can have a relatively capable virtual representation. This is sometimes termed a cyber-object or a virtual agent.

For example, a carton of milk can have a unique identifier and the ability to broadcast its presence to a local sensor (in the refrigerator, say). Somewhere else — it doesn't really matter where — a virtual instance of the milk carton can possess data about when it was bought and by when it should be consumed. This information could be reported back to the fridge: To the person who opened the door, it could appear that the milk "knows" whether its use-by date has been passed.

Sensitivity

As well as being able to report on its own condition, a thing can also report on different characteristics of its environment. A thing may have sensors to report temperature, humidity, vibration, location, or noise levels. A thing may also be able to record and/or stream audio or video information, if sufficient bandwidth is available.

But when is a thing a thing? For example, is a monitoring device stuck on the side of a bridge a thing, or is it the bridge? Is the thing just the physical object, or does it also constitute its virtual representation? The answer is either, or both: Outside the philosophical debate or the way the software is configured, it doesn't really matter.

Autonomy

A final characteristic of things is that of autonomy. Things need to be treated and monitored individually, usually from a remote point, and they must operate independently of a remote control. The concept of statelessness is important here: It is not for any massive computer system to take control of individual things in a totalitarian fashion. Rather, each thing is in some way responsible for itself, not least by maintaining its own view of state, which can then be interrogated by a third party.

Building upon this, things can exhibit various degrees of smartness. It is perfectly reasonable to consider a thing — either with onboard capabilities or in conjunction with its cyber-representation — to have awareness or even a level of decision-making capability. To keep heat inside a house, for example, a garage door could “decide” to close itself if the outside temperature is dropping and no activity has been sensed for a certain time period.

Bringing it all together

These characteristics not only enable physical items to gain new capabilities but also permit the creation of new things such as weather stations or surveillance cameras. We examine these more in the next section. For now, keep in mind that the opportunity is not simply to create smarter devices or support better remote monitoring. As our definition suggests, the internet of things is more about what such capabilities enable:

“The internet of things is an ultra-connected environment of capabilities and services, enabling interaction with and among physical objects and their virtual representations, based on supporting technologies such as sensors, controllers, or low-powered wireless as well as services available from the wider internet.”

Building the internet of things

We've seen the kinds of characteristics that things require to achieve their potential. So how are suppliers working to deliver the kinds of capabilities involved? The supplier market is dividing into companies creating foundation capabilities such as tags, sensors, and hubs, alongside software and services companies innovating on top with automated support, business process integration, event management, and data analysis.

Hardware and sensor components

The wide variety of component manufacturers operating in this space makes any kind of taxonomy impossible. Traditional semiconductor companies such as Intel, LG, Samsung, Broadcom, Texas Instruments, STMicroelectronics, Freescale (spun out of Motorola in 2003), and NXP Semiconductors (spun out of Philips) are being joined by more-recent startups such as GreenPeak Technologies and companies originally focused on specific verticals, such as Fairchild Semiconductor and Anaren in defense or Bosch and Schneider in production and utilities.

Sensor devices can include accelerometers, heat and humidity components, pressure components, cameras, and microphones, indeed anything that can generate information abut the status or environment of a thing. As well as larger manufacturers, companies like Knowles Electronics, InvenSense, and Altair also play in this space.

Meanwhile manufacturers are building microcontroller units (MCUs) and processing units. Atmel's MCU is being used in Samsung's latest smartphone, the S4. There is a clear trend toward integrating multiple capabilities in a single device. We are seeing full-fledged sensors incorporating a system-on-a-chip (SoC) design, such as GreenPeak's sentrollers.

Does opportunity exist? Undoubtedly, but not without risks. Competitive advantage comes from offering elements of a reasonably limited functionality set — processing, control, and sensor technologies — in the smallest possible size and power footprint. As interest grows, we will see market consolidation. Qualcomm, for example, has bought wireless chip maker Atheros.

Communications components and protocols

Investigating the passive world of things first — think bar codes and QR codes — offers the simplest possible way to identify a physical object or its type and should not be ignored.

On top of bar codes and QR codes, the main focus of activity in communications is in smarter chip design. RFID and associated technologies are advancing apace, particularly as the cost of such devices reduces. As well as the inserts familiar to physical book and film purchasers, RFID capabilities are being built into other components. For example, DeviceFidelity has released a microSD card that acts as both a passive tag and an RFID reader, enabling a mobile phone to be linked to a bank account and used in mobile payment transactions.

NFC is seen as the two-way successor to RFID. It enables information to be sent from devices as well as received, which allows the communications mechanism to be controlled by a software app. While it still only has a usable working distance of 20 cm, NFC also incorporates functionality such as data encryption.

To enable active communications over greater distances, manufacturers are not ruling out any option. In addition to Wi-Fi and Bluetooth and all flavors of cellular from GPRS to 4G LTE, options include:

- **Z-Wave.** This is a proprietary home automation communications protocol from Sigma Designs that has been incorporated in security and alarms, electricity meters, thermostats, and light switches.

- **ZigBee.** This is a mesh networking protocol designed for very low-power environments. It incorporates energy harvesting. For example, the energy generated by flicking a switch may be sufficient for a device to communicate.

As with other components, a size and power race to the bottom is driving a great deal of activity in this area. Devices are being created that can operate on less than 1 volt (i.e., a single battery) or use solar power or harvested energy from the likes of EnOcean. In February of this year Broadcom launched what it claimed to be the smallest 4G LTE chip, and Redpine Signals released a combined Bluetooth 4.0, Wi-Fi, and ZigBee chip.

Larger mobile communications companies such as Vodafone and Verizon as well as startups like Sigfox are also keen to get in on the act in the recognition that their infrastructures may well provide the backbone for thing-generated data.

Controller boards and platforms

Whole boards are increasing in complexity even as they are falling in cost. For example, the original Arduino board (designed to help teach electronics in schools) was based on an Atmel AVR 8-bit microcontroller chip. More recently manufacturers have released a 32-bit board based on the Atmel

SAM3X8E ARM Cortex-M3 CPU. In other words, what was seen as a low-level though highly programmable circuit board has evolved into a full-fledged computer.

The current darling of the industry is undoubtedly the Raspberry Pi, which is based around a Broadcom BCM2835 system on a chip. While founders expected to sell between 3,000 and 4,000 units, largely to UK schools, by January 2013 over a million Raspberry Pis had been shipped. The device is now being distributed in Asia, with the U.S. to follow. Not stopping there, the UDOO board combines both an Arduino-type MCU and a quad-core processor, which is equivalent to four Raspberry Pis.

From an onboard software perspective we are seeing a number of innovations. Beyond firmware, embedded operating systems such as Linux are familiar. Meanwhile devices are sending SMS messages and tweets, as well as hooking into open messaging platforms such as Jabber. Cisco, for example, has a working example of how such message passing can enable lights to be switched on when users enter an office as well as enabling their location status to be updated.

The rapid growth of board manufacturers such as Raspberry is a good indicator of the strength of opportunity in this space. While major reference architecture players such as Intel have not really engaged, the market remains wide open for controller board designs and products, which can serve as the basis for widespread adoption. M2M players such as GE, Bosch, Siemens, and Schneider may well become market leaders as they adapt their own platforms for more general-purpose use.

Clearly, it is only a matter of time before a single board can perform a complete set of functions expected of the things it supports. To win the market, manufacturers will need to make their own offerings as low cost and simple to adopt as possible, either through the adoption of open standards as they emerge or by becoming the de facto choice.

Things

An internet of things market discussion would not be complete without considering things themselves. The consumer space represents a new set of opportunities. Given that no boundaries exist on what constitutes a thing, potential examples are legion, but we are seeing significant interest in the following:

- **Health monitoring devices** and associated online tools, such as Fitbit (see disclosure) for general health monitoring and Corventis, a wireless cardiac monitor
- **Household device monitoring** including Supermechanical's Twine and SmartThings, which raised $1.2 million on Kickstarter

- **Environmental monitoring** tools such as the Netatmo weather station for meteorological data or the Nest intelligent thermostat, which learns the heating properties of a home and controls the boiler accordingly
- **Tracking tools** including the Tractive pet tracker and Omnilink for tracking cars, offenders, and a variety of assets
- **Power management and control** including Belkin's WeMo, Ninja Blocks, and the Revolv (formerly Mobiplug) hub. These enable devices to be controlled from a central point
- **Entertainment** things, such as the just-for-fun Bubblino, a device that blows bubbles when certain keywords appear on Twitter

Concerning the broader industry use of things, we do not dwell on the M2M sensor market here: Industrial monitors and controls continue to develop. We recognize, however, the potential for new device types in a number of sectors, not least, for example, in agriculture, where self-driving tractors, automated fruit pickers, and even robot bees are being researched.

At the moment the consumer market for things is, to put it mildly, fragmented. In some ways it reflects the market for smartphone apps shortly after Apple's launch of the iPod touch back in 2007. This is no bad thing: As prices drop and consumers get into the home-monitoring groove, for example, the market could be tremendous.

Prices may have to drop quite substantially, however. Twine, for example, remains out of reach for the majority; its price point would have to drop $99 to become affordable. On the upside, it is not hard to predict the internet of things–equivalent of *Angry Birds* — that is, a low-cost device that takes the world by storm. For the company that manages to achieve the right combination of functionality, price, and reach, the rewards could be phenomenal.

(**Disclosure**: *Fitbit is backed by True Ventures, a venture capital firm that is an investor in the parent company of GigaOM. Om Malik, the founder of GigaOM, is also a venture partner at True.)*

Management and infrastructure

Beyond devices, a clear need is developing for thing-management software, an area Qualcomm is addressing with its AllJoyn platform, ThingWorx with its development tools, and Lhings with its own cloud-based offering. Meanwhile LogMeIn has partnered with ARM to develop a cloud-based monitoring platform for things, based on ARM's Mbed module and workflow and the Xively (formerly Cosm, based on the Pachube technology) platform. In addition, the If This Then That (IFTTT) online rules engine can work with messages coming from things, for example to forward an email or tweet if a status message is received.

To extend such capabilities into the enterprise, Bosch Software Innovations' internet service platform enables things and the messages they generate to be integrated with business process management tools, for example, to trigger a response to a customer event. Ericcson, Cisco, and other networking vendors also offer solutions. Meanwhile cloud software vendor Evrythng enables the integration of thing-based events with marketing and sales processes.

Both business and consumer markets remain wide open, however. Research firm Analysys Mason found that while a number of vendors offer business solutions, none offer the complete range of capabilities required to fully manage things. We expect to see traditional management players, such as IBM, HP, BMC, and CA, also developing or acquiring capabilities in this area as well as mobile device management software companies such as Symantec. Indeed, CA has recently bought Layer 7, an API management and security company.

Meanwhile, in October 2010, the European Union launched the Software Platform for Integration of Engineering and Things (SPRINT) with industry partners including IBM and EADS to look at architecture and reference models for things. In November 2011 this joined the Open Services for Lifecycle Collaboration (OSLC) initiative, again focused on architecture and integration.

Data management and analytics

The internet of things is already creating a wealth of data, adding petabytes to the mountain being created by corporate systems, social networks, and other computational tools. Status messages, sensor feeds, and audio and video streams need to be stored and managed. While this could be done locally, the logical place (in architectural terms) for internet of things–generated data is in the cloud, using storage from providers such as Amazon or Microsoft. Companies like Salesforce.com are already considering how such data can feed their own application platforms, and IBM has recently announced a service to enable the management of data coming from internet-connected sensors and devices.

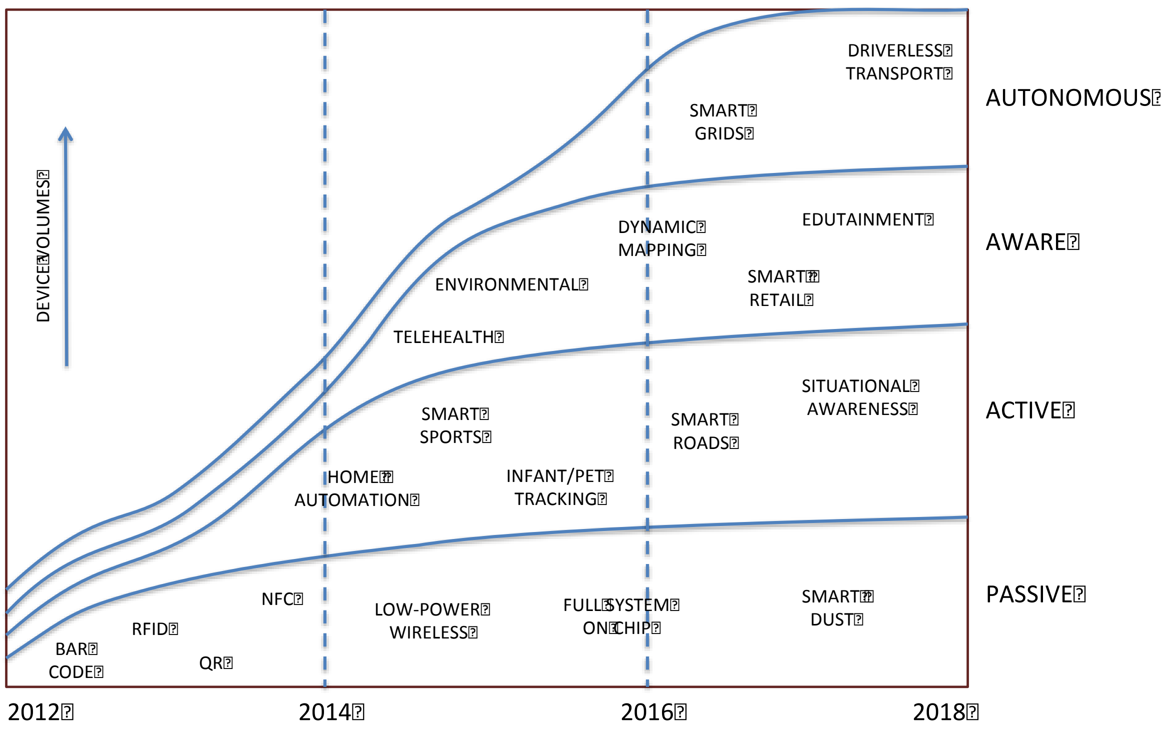
A major opportunity comes from making sense of all of that data. Data management, algorithmic, and analytics companies such as SAP, IBM, EMC, HP, Splunk, Tier-3, and BearingPoint already have the tools required to find needles in the haystack of thing-related data. Use cases, which we consider below, could be anything from identifying a security breach or a manufacturing process fault to ensuring that sufficient bicycles are in the right locations across a city.

The internet of things market evolution

As we stated in the last section, development and innovation is taking place at all levels of the internet of things, from components up to advanced data analytics. We believe that the market will develop in a similarly incremental fashion, as innovations at each level consolidate into overall waves of market evolution, depending on the volumes of things shipped, by type:

- **Passive things** are in some way remotely identifiable and connectable but relatively dumb. RFID-tagged books, furniture items, and spare parts fit into this category.
- **Active things** can exchange sensory data, control information, and gain a level of interaction. Foodstuffs, farm animals, roads, and bridges are examples here.
- **Aware things** can process data and take action in response to events. This includes doors and windows, driverless trains, and electrical appliances.
- **Autonomous things** can make decisions based on built-in rules running locally or remotely. As well as intelligent thermostats and smart grids, examples include self-driving cars.

As innovation proceeds, we expect to see the internet of things market move from where it is currently, involving higher volumes of largely passive things, to a market that incorporates large volumes of autonomous things in four to five years' time.



For illustration purposes only

As seen in the above figure, volumes shipped are incremental because market development of aware things will not reduce the volumes of active things shipped. We do not expect all things to achieve autonomous status. For many requirements, it simply isn't necessary to do so. However, over time we will see an increasing level of smartness across the board.

What does this mean in terms of market opportunity? According to a May 2013 report from research firm MarketsandMarkets, the internet of things and M2M communications market will reach $290 billion by 2017, growing at 30 percent per year. Given the incremental nature of the market, we would suggest that:

- Shorter-term opportunities (1–3 year time frame) will come from active and aware things. This means more focus on the things themselves: Look for the things equivalent of the killer app, with less emphasis on backend or cloud-based management and analytics.
- Medium-term opportunities (2–5 year time frame) will come from aware and autonomous things. This implies more focus on infrastructure and platforms that can pull together the management of things and the data they create.

How disruptive will the internet of things be to existing markets? Outside M2M, much of the internet of things is net-new. In other words, it doesn’t directly replace anything that has existed before, particularly in the consumer space. However, the winners in terms of component manufacture, platforms, and infrastructure in particular stand a good chance of gaining market leadership positions overall, just as we have seen with Amazon and Google in the cloud space, Facebook and Twitter in social networking, or Apple and Samsung in mobile devices.

We look at where this growth may come from in the next section.

Early-adoption scenarios for the internet of things

There are already many examples of where the internet of things is coming into play. We've mentioned the role of things in manufacturing and production, utilities, supply chain, retail, and transportation. These models will extend and evolve. Consider how GE has coined the term "industrial internet" to describe its own vision and strategy for mechanical and plant engineering.

But what about broader adoption, extending beyond M2M and moving into the enterprise and consumer environments? The internet of things is about convergence, bringing capabilities seen in more industrial and niche fields to a much wider audience. We are already seeing a number of usage scenarios today.

Identification and tracking

Just as identity is the most fundamental characteristic of the internet of things, identification and tracking are the most common applications to date. Where the benefit of knowing where things are outweighs the cost of doing so, that's what's being done. Look to Viloc's solutions track construction equipment and tools as a good example of this.

Many passports now have RFID tags in them, as do hotel room keys and ski passes. Animal tracking is also a common use case: Tracking devices can be injected into pets, and following the BSE (mad cow disease) crisis in the UK, RFID has become a staple identification and tracking mechanism for livestock.

In sports, baseballs are being equipped with tags, and a number of football unions are adopting goal-line technology (e.g., smart football nets) to help umpires and referees make decisions. And tags enable the provenance and authenticity of artworks and sports memorabilia to be checked.

Monitoring

Environmental monitoring is another growth area for the internet of things, and for a good reason. For example, there is value in having a device in the home that can report whether or not gas can be detected in the air. Affordability is the only reason it does not yet exist in applicable homes.

Smart roads and bridge-monitoring sensors are also being used increasingly to dynamically map transport conditions. In Boston, these have been linked to taxi-mounted sensors that can identify and report potholes. In the future, researchers are looking at using solar energy in parallel with sensors to heat parts of roads that are frozen or to turn on streetlights as cars approach.

Integrated control

Given that electronic devices are a mainstay of health care delivery, there is a clear benefit in connecting them together. Furthermore, it's not just heart monitors, X-ray machines, and the like that are becoming increasingly part of an overall technology fabric. Hospitals and other health care services are piloting the use of control apps on tablet computers or even smart pens that can automatically upload patient notes as they are written. The ability for health care professionals to gain immediate access to all such information — and therefore make better, more-immediate decisions — is compelling.

The home is getting smarter, too, or at least the devices and appliances are. We can already see the way that televisions and set-top boxes (the latter being computer-based, after all) are gaining Wi-Fi connections and the ability to run simple applications. Companies like LG and Samsung are extending these ideas to other appliances. After all, why shouldn't the washing machine be able to broadcast when the washing cycle is complete?

Predictive business analysis

Analytics is a well-established field, and it is reaching a tipping point (characterized as big data) in terms of the quantities of information that can be dealt with (using tools such as Splunk, for example) and the rate at which it can be interpreted.

Algorithms exist that can watch data streams, building a picture of what is normal and then triggering alerts when something unexpected happens. Australian software firm Tier-3, for example, has deployed its Huntsman anomaly detection technology in domains including computer security, manufacturing, and financial services. Meanwhile BearingPoint's HyperCube solution processes large quantities of data and draws up rules to explain anomalies so that they can be watched for in advance.

Such approaches are useful in manufacturing, when it can be cheaper to predict and prevent mechanical failure than it is to make repairs. Using a combination of sensors and predictive analytics, it is possible to identify, assess, and respond to potential faults before they occur.

Early response

Of course, there's more to the internet of things than simply knowing a bit more about what's going on. Knowing where things are and their state allows consumers to also make decisions about them. For example, defense organizations also see the potential of the internet of things in military operations, as information becomes key to both strategic and tactical success.

The idea and discipline of situational awareness, which involves building a picture of a situation and assigning roles and actions, come from military and public-crisis response best practices, but they have been applied in other contexts: Take the City of Chicago, which provides parking and snow-clearance services to its citizens.

Meanwhile the field of tele-health is extending beyond simple health monitoring of the infirm or elderly. In the UK, a remote monitoring system triggers events should there be an issue, which can result in an ambulance being sent automatically without the need for a call. It is not hard to envisage a device based on simple body health monitoring and an accelerometer to identify whether a person has suffered from a fall.

Efficient processes and service delivery

Above all, the internet of things should be able to make processes more efficient by augmenting existing interactions and activities. The concept of contactless payment is becoming increasingly familiar, for example, though it remains limited to certain niche applications such as public-transport payment cards or automatic payments on toll roads.

More-advanced scenarios use a variety of characteristics of the internet of things to deliver services in new ways. Consider the Car2Go network of pay-as-you-go cars in Austin, Texas. This uses automated payment and remote monitoring and tracking of vehicles to provide a service in a way that would not have been possible before, restricted either by technology or cost.

In the workplace, the internet of things can link into business processes to improve productivity and reduce the costs of doing business. According to a survey from SAP, 65 percent of IT decision makers felt the biggest opportunity for M2M was increased workforce mobility — that is, enabling staff to work more efficiently when they are outside the office.

Where should organizations focus their efforts?

Across the range of usage scenarios we list here, the primary benefit is efficiency: enabling services to be delivered at a lower cost. In some instances this enables new service types (such as metropolitan car hire), but many organizations will be able to benefit from the internet of things by augmenting existing activities and services.

Outside M2M, for obvious reasons verticals and business areas with greater interaction with the physical world stand to benefit the most within the next two years. Of particular interest are the following areas.

- **Health care** is already making use of telehealth systems and services, an area likely to grow substantially over the coming years both inside hospitals and across community service delivery.
- **Agriculture** is looking to combine sensor data (such as soil analysis) with environmental data, satellite imaging, and so on.
- **Physical retail** is known to be struggling, particularly in light of lower-margin ecommerce. The future of physical retail lies in delivering improved experiences to customers, enabled by the internet of things.
- **Public safety and defense** can benefit from the increased use of sensors and monitoring, combined with information from broader sources (environmental, geospatial, and so on).

What might slow down adoption? We look at this in the next section.

Potential inhibitors to the internet of things

Technology is never a bed of roses. Just like any other advance over the past few decades, the internet of things is going to bring with it a number of challenges, risks, and negative connotations. Security is of course a factor, which goes hand in hand with the inevitable (and in some cases merited) privacy fears that many will express. The technology itself could operate suboptimally, causing inadvertent problems through design or poor deployment. In the spirit of "forewarned is forearmed," let's take a look.

Security challenges

Computer security, say the experts, boils down to protecting the confidentiality, integrity, and availability of both data and services. With the internet of things looking set to create all manner of data, from heart rate and baby monitors to building management systems, there is clearly going to be a great deal to protect. Some issues could come from weaknesses in the hardware. In 2006, for example, two hackers showed how they were able to clone an RFID signal.

More troublesome are the signs that we will be our own worst enemies, leaving gaping holes in the way we configure things and then allow them to deliver information. For example, the Shodan search engine was launched in 2009 to search internet-connected devices using the SCADA protocol, including their vulnerabilities. This became extremely topical a year later, when the Stuxnet computer worm, which also targeted SCADA devices, reared its head.

Not that the situation is any better today. In 2012 the Carna Botnet discovered 165 million IP addresses that had left important IP ports open. "A lot of devices and services we have seen should never be connected to the public Internet at all," said the research. "Four simple stupid default telnet passwords can give you access to hundreds of thousands of consumer as well as tens of thousands of industrial devices all over the world."

As well as enabling access to data, cybercriminals could have a profound impact on device configurations and their capabilities. Movies portray frequent examples of hackers remotely opening doors or safes. These examples are perfectly feasible if access building management systems are infiltrated. Researchers have shown how insulin pumps and pacemakers are also vulnerable to attack, either using NFC or, if they are internet-connected, from anywhere in the world.

It is possible to protect against such risks using data encryption, more-stringent authentication, and other methods. But as we have already noted, such standards have yet to be rolled out.

Privacy and surveillance

The internet of things enables the whole world to be monitored. When the World Wide Web became mainstream, Scott McNealy (then running Sun Microsystems) famously said, "Privacy is dead. Deal with it." While we may be nervous about out online privacy, we haven't seen anything yet.

At a low level we are already seeing the issue of skimming. Look at passports: Despite having a working range of 20 cm, the first RFID-equipped passports were found to be readable at distances of up to 10 meters. In the U.S. this led to the state department adding a metal lining into passports. A PIN code mechanism is also in the pipeline.

Privacy may become a concern for civil rights groups. Already, London is perceived as the most CCTV-heavy capital city in the world. However, the challenge also comes from corporate and consumer technology. While it may not become impossible to hide one's location, it will get increasingly difficult, and the potential for the inappropriate use of such technologies — for example, to spy on partners or offspring — will grow. In the business context as well, the role of the internet of things offers a wealth of opportunity but also of abuse.

As our digital footprints become increasingly marked, studies suggest that individuals recognize a trade-off between convenience and the concerns raised. A wide variety of questions from the recognition of responsibilities, the role of de-identified data, and the right to be forgotten all need to be debated, resolved, and put into legislation and action. Equally as we make such trade-offs and reach conclusions, the concept of trust of our public and health care services, of businesses, and even of peers will grow in importance.

Meltdown

An additional danger comes from our reliance on technology. In general, if anything goes wrong with the technologies we use, we can get on with our lives. But what if we come to find our expectations of the internet of things are not met?

We have already seen examples of technology's adverse impact, such as the avalanche effect in trading, in which a poorly constructed algorithm can cause a listed company's share price to crash. It is possible to imagine similar scenarios in our IoT-enabled world. Might we end up locked out of our houses, run out of food or gas, or see large-scale manufacturing systems failure? What if we find the things we depend on have been victims of planned obsolescence on the part of their manufacturers?

Beyond this point, we head into the unknown. Will the internet of things realize such a state of autonomy that devices take control, in a Skynet-like future? Or will smart dust and nanobots infiltrate our every pore? The answer is possibly but not for a long time. Nobody needs to head up into the mountains just yet.

Trends and technologies to watch over the next 3 to 5 years

The internet of things is changing the way people and organizations engage with the world around them. Yes, this opens up new opportunities, but it may be that we are still scratching the surface of what we can do once we can monitor and control just about everything.

We have a number of expectations in terms of how trends and technologies will evolve and further drive opportunities for the internet of things.

Standards and norms will consolidate and merge to provide a platform for the internet of things. We are already seeing this at the board level with emerging norms such as the MQTT communications protocol for sensors, which IBM is looking to standardize. However there are no standards yet for onboard operating systems used by certain classes of things, nor the APIs they offer. Neither is there any real legislation, which responds sufficiently to the needs of a world in which anything can be monitored.

Similarly, while the tools available to monitor, manage, and otherwise interact with things are proliferating, at this stage they remain proprietary. The acceleration of the internet of things will require open tools and frameworks to be established, as illustrated by the efforts of the Open IoT Assembly in London in June 2012 to establish an internet of things bill of rights.

Miniaturization will continue apace. We have noted how reduction in size, power footprint, and therefore cost is a key enabler to the internet of things. In principle the only barrier to making things smaller is that dictated by the laws of physics: The term "smart dust" has been used to characterize ultrasmall, self-powered, intrinsically disposable devices.

Before we arrive at this point we will see more and more items we consider things. Just look at how researchers have created RFID-enabled paper for use as bank notes or computers that can be swallowed.

Mobile technologies remain on the watch list, despite the fact that smartphones and tablet computers are now part of the mainstream. Such devices already have accelerometers and GPS functions built in. They also — to state the obvious — play host to a wide variety of applications.

We expect existing mobile devices to grow in capabilities, not least by incorporating a broader range of the characteristics we present here (such as NFC, temperature, and other physical sensors). They will become coordination points for things within the home and in business environments. And they will continue to diversify in form as well as function (e.g., smart watches).

Cloud technologies are likely to drive a significant amount of innovation because of the level of scalability they afford. The architectural models behind highly scalable, real-time messaging services such as Twitter or Facebook are an excellent fit for the possibilities and challenges that the internet of things will bring.

Equally, these are no more than a foundation. We expect to see numerous startups create innovative thing-based services through new collaborations. Consider LogMeIn and ARM's Xively, for example, or Salesforce.com's launch of its Social.com platform, which links the internet of things to social tools and a big data backend.

3D printing is a potential technology area to watch, given that it enables the creation of physical objects that can be augmented with sensors and controller boards. As well as the obvious application of making sensor casings, 3D printers and Arduino controllers are being used to create electromechanical hands.

UK researchers have printed electronic sensors based on a material they are calling carbomorph, and Princeton University has 3D-printed a bionic ear using cell tissue and an antenna.

Artificial intelligence was once going to be the pinnacle of the computer revolution, and we have seen waves of development in terms of how computers can make decisions autonomously. We expect the internet of things to drive new interest in this field.

We already mentioned the Nest thermostat, which can determine optimal temperature settings, having read the energy profile of a house. At the other end of the scale, smart power grids and smart cities look to deliver energy in the most efficient manner, taking into account usage patterns across a much broader sample. Self-learning, self-adapting, and even self-repairing systems could become a reality in the not-too-distant future.

Software-defined networking is an emerging discipline in which applications and software can access APIs of routers, switches, and other low-level networking devices. While this is currently being viewed as of interest to data center management, the question must be asked, What if networks could be controlled based on information coming from the internet of things?

The internet of things will no doubt grow and evolve in both concept and substance. As with many technological advances, it is as much about the journey as the destination. We shall see the impact across every domain, and our shopping experiences, personal interactions, and the ways we work, live, eat, and sleep will become an ever more intrinsic part of the infrastructures on which we depend.

From the internet of things to the web of everything

We've barely scratched the surface of what the internet of things can offer. Even the term itself starts to sound underwhelming once its full potential is considered. This is about far more than simply joining physical objects together. Rather, it brings them to life by providing a way that they can communicate with one another and with us.

Some are already looking beyond the internet of things toward a web of things, which broadens the scope to consider what the internet of things enables in terms of interaction and innovation. We would look beyond that still and consider an internet of everything: There is nothing in this physical world that will not, at some point in the future, be touched by technology.

The consequences of this will be profound for individuals, businesses, society, and the world:

- As **individuals**, the term "quantified self" has been mentioned to describe how we will be able to monitor every aspect of our bodies, mood, and behavior at all times. Again, who knows where this will end, given the research already taking place into brain activity measurement on the one hand and our ability to control devices with thought patterns on the other.
- How will **communities** respond? The societal equivalent of Heisenberg's uncertainty principle most certainly comes into play, in that the act of measurement has an impact on behavior. Correlations will be drawn between the most innocuous of data and deep insight.
- In **business**, the opportunities are legion both in the public and private sector, either to benefit from the positive use of things to make an organization more efficient and improve existing product and service delivery or to innovate on top of the internet of things in order to create and deliver new products and services for customers and clients.
- The impact on **world economies** will be equally profound. The web of everything has the potential to bring us together in ways we have never experienced, for better and for worse. Things can play a huge role in removing inequality and poverty; at the same time the risks will be felt at a national and international level. No doubt someone will create the equivalent of a dirty bomb in thing terms.

In terms of guidance, the advice depends on where you are sitting. For companies, the web of everything is predicated on the availability of huge quantities of processing and data management resources, so we would advise, if you do not have cloud and/or big data elements written into your IT strategy, you probably should.

In verticals with an M2M background, the opportunity is to broaden and in retail and supply chain environments to deepen work that is already taking place, building on existing systems and architectures. In other market verticals, the ability to harness the web of everything may be completely new. The kinds of use cases we list here should offer a starting point and food for thought for your own business.

Meanwhile as employees and consumers we can all benefit in our home and working lives, as long as we keep an eye on the risks, of course. Hobbyists and makers are creating the potential for a thing-based economy. Clearly, smart devices hold a more interesting and potentially lucrative future than dumb devices, and the broader community may be better able to spot and create the kinds of things that will make the most difference.

Ultimately, the future of the web of everything is in our own hands.

Key takeaways

- The internet of things describes a growing phenomenon in which every physical object can have some form of connection to the internet. The possibilities of what this enables are limitless.
- A number of characteristics describe such things, including identity, interactivity, shadowing, sensitivity, and autonomy. Not every thing needs to possess every characteristic, though things will become smarter over time.
- An ongoing opportunity exists for manufacturers of components and boards that turn ordinary objects into things. Competition is innovation-driven, corresponding to a race to the bottom in terms of size, power, and cost.
- Beyond things, new opportunities exist for software players to create the kinds of management frameworks, storage, and analytics tools to make sense of all the data to be generated by things.
- Market evolution will follow a number of waves, based on the adoption of increasingly smart things. The current largely passive wave will be superseded by active, and thence aware and autonomous, things.
- Early-adoption scenarios extend beyond traditional production and retail environments, employing machine-to-machine (M2M) monitoring and tracking. Remote control, predictive analysis, and early-response use cases are emerging in a number of business and consumer sectors.
- The internet of things will not be without its challenges. Security, privacy, surveillance, and the potential for disruptive systems failure are all potential risks that will need to be mitigated as the market develops.

About Jon Collins

Jon Collins is the principal advisor at Inter Orbis. Having spent 25 years in the technology industry, Jon has a deep understanding of the global technology infrastructures, architectures, security, and governance models required, as well as hands-on experience of delivery in a variety of sectors. Jon is co-author of the IT strategy book *The Technology Garden*. He has written numerous papers and guides about getting the most out of technology, and is an accomplished speaker, facilitator, and presenter.

In Jon's varied career he has acted as IT manager and software consultant, project manager, training manager, IT security expert, and industry analyst. In recognition of his insightful, yet down-to-earth approach, Jon was named European analyst of the year by the Institute of Industry Analyst Relations in 2009.

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