GIGAOM RESEARCH

Enabling IoT

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TABLE OF CONTENTS

Executive summary

While the internet of things (IoT) is creating quite a buzz in the media and despite the fact that it is built on solid foundations such as machine to machine (M2M) communications, these remain early days for the technology. With architecture standards and communications protocols still in their infancy, today's use cases tend to be custom-designed, using a combination of embedded sensors, gateway devices, networking communications, and backend services.

This report is aimed at embedded device manufacturers, telecommunications operators, and cloud service providers aiming to add value to their portfolios, as well as application developers and architects looking to respond to existing and new opportunities for IoT. It drills into what needs to be in place for IoT to deliver on its promise, with particular emphasis on how embedded devices integrate with cloud-based analytical services.

Key findings are as follows:

- From an architectural perspective, IoT extends the sensory network of the enterprise, enabling smarter decision making and faster response to events, potentially in real time.
- To be successful, IoT use cases need to fit with the way technology is being adopted by today's agile businesses. This means taking account of cloud-based software-deployment models as well as focusing on the early delivery of business value.
- Most use cases follow one of three architectures: ultra-thin, smart client, or peer to peer. Each relies on different combinations of technology elements, from embedded sensors and gateway devices to processing and analytics.
- A number of constraints exist, including reliability and responsiveness, simplicity and interoperability, and security and privacy. These create a threshold of acceptability against which potential use cases can be measured.

Introduction

Unlike many other emerging technology trends, IoT is grounded in more than just marketing hype. Its M2M-communications underpinnings are based on decades of operational-technology (OT) practice, while the monitoring capabilities involved have been developing across many years of innovation in retail supply-chain automation and other product-oriented industries.

The relentless advance of Moore's law is bringing IoT into the mainstream, broadening the range of opportunities to monitor, connect, and control physical objects through the use of embedded technologies, either within existing products or as separate devices. In the companion report to this one, "The internet of things: a market landscape," Gigaom Research defines IoT as:

> "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."

IoT takes organizations far beyond simply monitoring physical objects, incorporating sensors, or enabling remote control through the use of embedded devices. From an architectural perspective, the elements of IoT can be considered as the enablers of an extended sensory network in which:

- Embedded devices become fingertips, enabling reach, responsiveness, and control.
- The network is the backbone that enables the transfer of information and events in a timely fashion.
- Cloud computing represents the brain, offering a scalable analytical, big data processing facility.

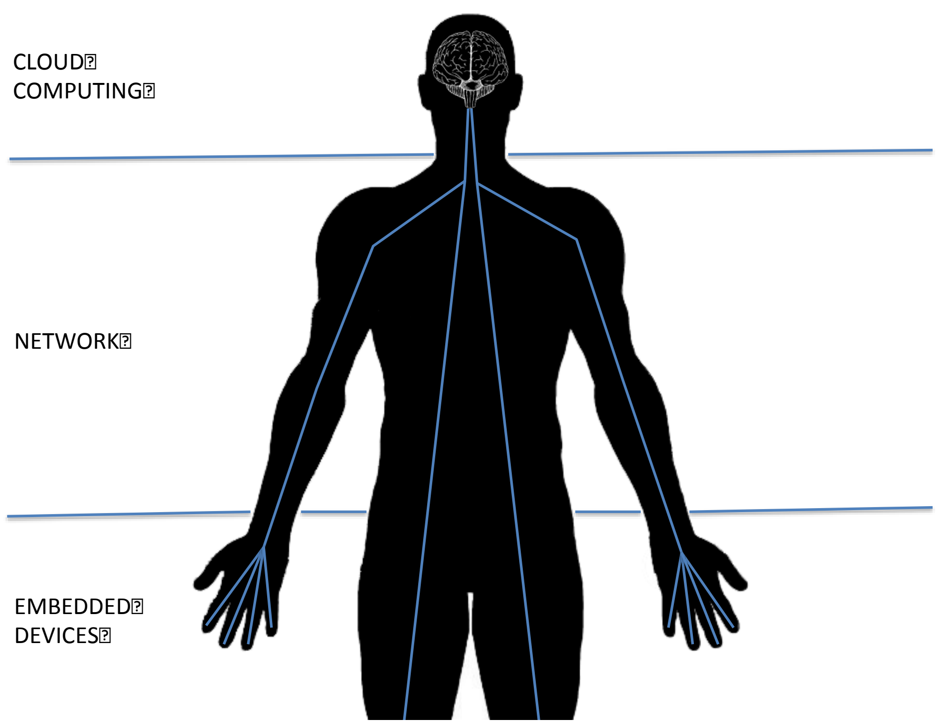
Just as the human body enables us to react to stimuli, make decisions, and carry out actions, this sensory network extends the reach and sensitivity of organizations to the physical environments within which they operate, enabling businesses and their staff to become more sensitive and responsive to their contexts, increasing both efficiency and effectiveness as a result.

This suggests a closed loop in which data is gathered from sensors, collated, analyzed, interpreted, and then acted on — in real time. As well as OT-based examples such as improved equipment monitoring, we are seeing applications across a wide variety of industry sectors, as we discuss below. As there is no restriction on what can be connected, the potential market for IoT is seen to be phenomenal. Figures from the GSM Association suggest that 25 billion devices will be connected to the internet by 2020; others suggest that this number could be far higher, given our growing ability to miniaturize the components involved, with the resulting downward pressure on costs.

As such, IoT is poised to impact businesses of all shapes and sizes as well as a variety of consumer domains. While potential use cases appear all the time, from parking sensors to smart paintbrushes, organizations remain unclear about where and how their businesses can gain from the use of IoT technologies. Beyond the traditional application areas and a number of pilot studies, examples tend to be quite specific to a single use case or business need.

We can nonetheless learn from these early examples about how IoT use cases can be designed, constructed, and deployed. This report examines the architectural models that are driving IoT, from simple event-response loops to more-complex structures that make the most of available resources from networks, cloud infrastructure, and embedded devices.

Architectural models



Source: Inter Orbis, Gigaom Research

IoT in the agile, smart business

No technology can be an end in itself: IoT use cases need to deliver tangible business value. Fortunately, given that IoT's heritage comes from well-established foundations in industry, decision makers do not have to look too far for larger-scale examples of traditional remote monitoring and control:

- Equipment-oriented organizations such as manufacturers and utilities have capabilities in place to enable fault monitoring and diagnosis.
- Logistics and retail firms have been using location tracking of physical goods to support both supply chain and service needs.
- Physical security equipment such as alarm systems and CCTV cameras have long been dependent on remote monitoring.
- By its nature, information technology consists of smart devices from networking elements to desktop computers and smartphones.

As manufacturing costs fall, driven by both Moore's law and the economics of supply and demand, the market is expanding to accommodate a broader range of use cases that build on these examples to deliver on the principle of a more actively responsive sensory network driven by cloud-based analytics. Current examples include:

- Smart, secure buildings using a combination of connected thermostats and motion and room sensors
- Equipment sharing and theft protection of construction and plant equipment through the use of embedded or attached devices
- Smart city applications such as preemptive refuse collection, parking space allocation, and intelligent traffic routing
- Tracking people and animals across scenarios from patient monitoring and theme parks to agriculture and conservation
- Predictive maintenance, for example linking device sensors to parts-ordering systems to mitigate failure risk and reduce resolution times

Such use cases exist not only because they add value for businesses but also because they make economic sense for device manufacturers and suppliers. While some vendors remain focused on components, many are looking at how IoT enables new revenue streams by selling value-added services or monetizing the information generated. For example, one paint supplier is considering how IoT can reduce the overheads of commercial decorating companies through the more efficient delivery of wall paint. This requires not only passive tracking of existing resources but also predictive assessment of future demand.

As IoT accelerates into the mainstream, business decision makers may wonder how it can benefit their own organizations. Given that CFOs will not act unless they see a clear financial benefit from doing so, a given IoT use case needs to deliver tangible value in terms of either:

Increased efficiency. Reducing the costs of running the business (for example, a shorter time to resolve faults), creating better product quality, or wasting less.

Increased effectiveness. Achieving measurable financial benefit, for example increased productivity or sales.

Furthermore, in today's fast-moving business environments, technology needs not only to support the business but also do so quickly. Business leaders are focused on agility — that is, the ability to react to changing circumstances. Organizations today are highly resource-constrained and faced with a variety of pressures, meaning that little room exists for large-scale, higher-risk infrastructure projects.

Such constraints have a direct impact on the kinds of IoT projects that businesses can undertake. While room still exists for larger projects, bespoke applications, and built-in smartness, a more acceptable approach is to integrate existing components, enabling solutions to be constructed within a tighter time frame.

We already see this approach driving cloud computing deployments and mobile app development, both of which have been catalyzed by the general economic downturn and a recognition that ad hoc deployment of new technology is not a guarantee of business success. From an IT perspective, the result is a thriving API economy with a cloud-based backend, creating new possibilities for application builders to mash up real-time event analysis and other services. IoT solutions can build on the same capabilities.

In summary, rather than seeing IoT as an isolated technology area, agile businesses can view it as building on the cloud and mobile models and approaches, enabling organizations to extend their reach and responsiveness to events. This provides the backdrop for how we can consider the architecture of IoT.

Architecting IoT infrastructure

While smart devices undoubtedly help, IoT is not simply about what it can connect, individually, to the internet. Rather, successful business use cases enable a broader problem to be solved (saving money or reducing risk) or service to be delivered (increasing revenue).

From an architectural perspective, configurations for IoT comprise the following key elements:

- **A sufficiently large number of physical objects** possessing similar domain attributes and that could benefit from some kind of centralized coordination and control and either contribute to or benefit from shared and distributed as well as enhanced intelligence. For example, these could be patients in a hospital, trees in a forest, animals on a farm, or cars on a highway.

- **Embedded passive sensors or active devices.** Embedded devices of all shapes, sizes, and levels of complexity act as the fingertips of IoT. Devices can be passive or active, the latter potentially including some basic processing capabilities. These use a variety of message and event passing protocols, for example lower-level MQTT[1] or higher-level XMPP[2] for asynchronous message exchange.

- **Local processing.** Local hub devices enable events to be collated, interpreted, and delivered to the cloud in an efficient and secure manner. For example, image information can be processed or threshold rules tested locally before sending on relevant data or events. While this could be a locally installed computer, it is worth calling out smartphones as potential hubs, as they combine networking, processing, sensors, and human interaction.

- **Multi-protocol gateway capabilities.** Given that the number of protocols and data types in use across individual devices and sensors is still diverse and occasionally proprietary, gateway technologies from the likes of Wind River, Intel, Cisco, and Freescale enable events to be collated. Gateways can also build in security and manageability features, which are often lacking in individual sensors and devices.

- **A connectivity layer of suitably low latency.** Providing the backbone of IoT, the connectivity layer encompasses wired and wireless communications protocols from device-specific ZigBee or

[1] *Message Queue Telemetry Transport (MQTT) is a transport-level protocol based on a publish/subscribe communications model.*
[2] *Extensible Messaging and Presence Protocol (XMPP) is a higher-overhead, XML-based technology, originally called Jabber and used for instant messaging.*

Bluetooth through Wi-Fi and 2G, 3G, or 4G mobile to local networking and the wider internet. Note that not all use cases require objects to be constantly connected.

- **A scalable storage capability.** Given the event-driven nature of IoT's sensory network, storage requirements can be difficult to define in advance and are easy to underestimate. Generated events can be stored and preprocessed locally, for example in a relational database; online storage options using more-scalable NoSQL approaches include Xively,[3] TempoDB, and Aeris.

- **Cloud-based processing.** For IoT to be about more than simply remote monitoring and control, it requires a scalable computing capability to collate, interpret, and analyze potentially large volumes of information. While this capability can be delivered on in-house servers (particularly if security or latency are concerns), the scalability requirement can make cloud-based services such as Amazon Web Services (AWS), hosted Hadoop, or Splunk a more attractive option.

- **A management and control system.** This enables centralized monitoring of physical objects as well as rules to be set around what to do when certain events occur. It may also enable control of end-point devices, for example enabling adjustment of heating and air-conditioning units in a building. "Thing management" also needs to incorporate such topics as firmware updates to the embedded devices at the edge.

By looking at these elements as an ensemble, we can see what differentiates IoT from previous trends and how it will continue to develop and mature. Each of the above incorporates a number of constraints and trade-offs. For example:

- Embedded devices may be small and low power, but smaller devices can only perform more-basic functions.

- Cloud processing may be highly scalable, but it requires a great deal of power and can become cost-prohibitive.

- NoSQL approaches are good for high-throughput data processing, but they are less resilient than more-traditional data-management techniques.

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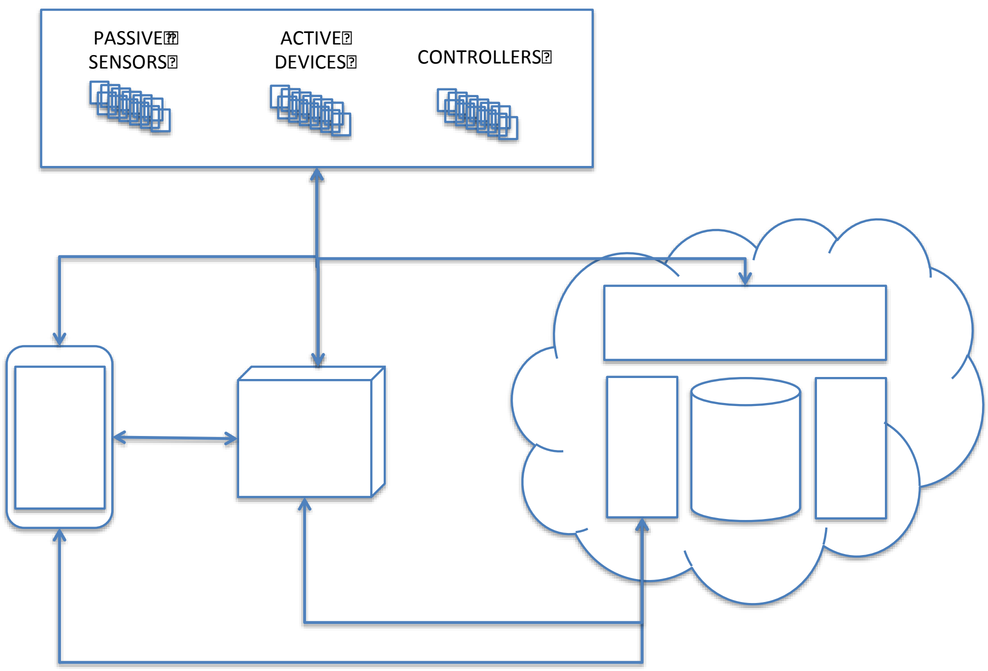
[3] *Formerly Pachube*

The result is that system and solutions designers need to choose the right architectural approach that takes these constraints into account. Nothing is stopping a manufacturer from creating a new type of device that combines some of the above — for example, an embedded device with some pre-analytical capability. Equally, an organization may choose to host its own scalable processing or analytics capabilities in an enterprise data center if it can define the requirement sufficiently well. Indeed, as is the case with web-based applications, it is likely that organizations will trial IoT use cases using cloud-based services, retaining the option to bring them in-house at a later point.

Overview of IoT architecture



Source: Inter Orbis, Gigaom Research

While all options are open, in practical terms a number of architectural models are emerging that satisfy the majority of current IoT use cases while delivering on the sensory-network principle of real-time responsiveness, as follows:

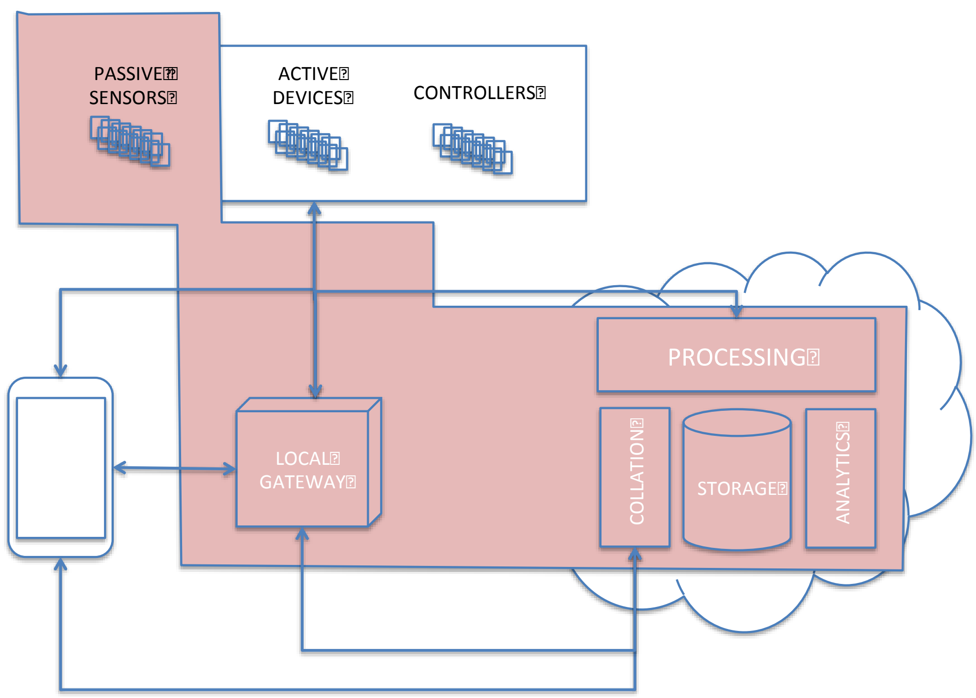
- Ultra-thin client, hub-and-spoke model

- Front-loaded embedded devices with local preprocessing
- Smart client, enabling peer to peer

Ultra-thin client, hub-and-spoke model

In this model, little intelligence exists at the device or physical object, which will tend to involve either a passive sensor or a very low-powered device with minimal local processing, as shown in the figure below.

Ultra-thin client, hub-and-spoke model



Source: Inter Orbis, Gigaom Research

The ultra-thin model relies on a local gateway to:

- Assure the security of the local environment — for example, such that only authorized sensors are able to transmit information

- Integrate with the required backend services, using appropriate protocols and standards
- Collate and forward generated information and events for server-based analysis, potentially with a level of preprocessing

This model is familiar in the traditional retail environment, including the use of passive RFID as an anti-theft mechanism. It also works well for devices that derive power from actions, such as action-sensing switches or pressure plates. From an IoT perspective it can also be considered for applications such as:

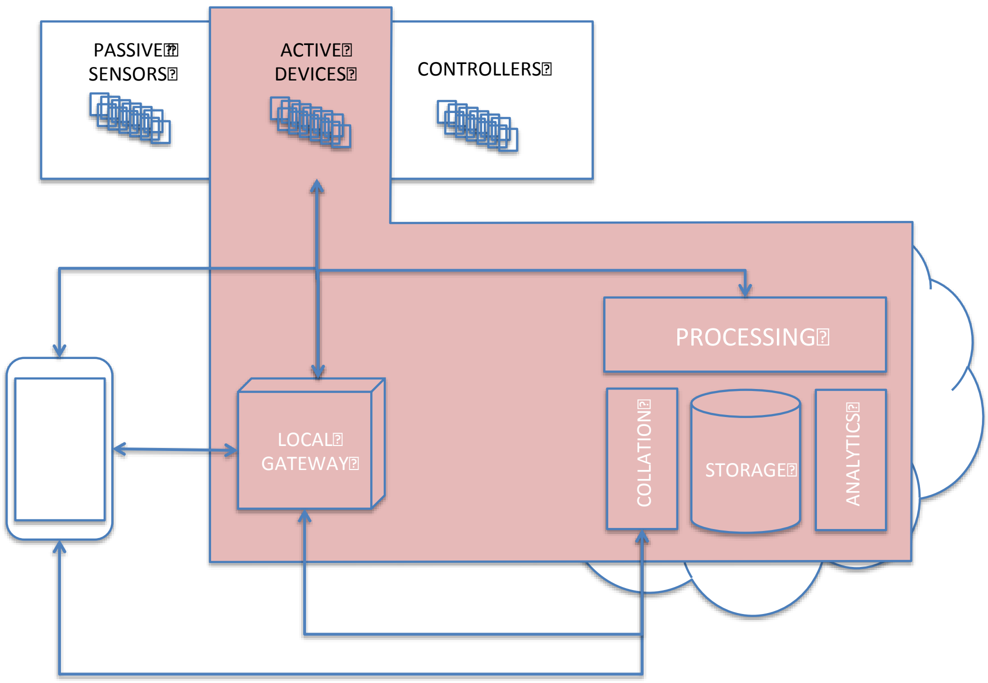
- Smart storage, including the infamous-yet-unlikely smart fridge; more likely are examples involving storage of higher-value assets across a longer term, taking environmental factors into account.
- Building automation. A common example is the Nest smart thermostat, which collates and forwards data from room thermometers. This data can then be used to create a profile for a property and learn how the house heats and cools and therefore how to heat and cool it efficiently.

Front-loaded embedded devices with local preprocessing

In the front-loaded embedded devices with local preprocessing model, local sensors and devices are active rather than passive, possessing some kind of local processing as well as more-powerful wireless capabilities that enable a direct connection to a network router.

With this model it becomes possible to perform a level of preprocessing of data and even automation within the local gateway — for example, testing events against threshold rules (see figure below).

Front-loaded embedded devices with local preprocessing model



Source: Inter Orbis, Gigaom Research

Devices built in the style of the Raspberry Pi, Arduino, or Intel's Galileo boards fit this mold, as do boards from companies such as Libelium. Examples include:

- Multiple applications are being piloted in smart city environments — for example, the use of electromagnetic sensors to create smart parking spaces.
- Tele-health monitors perform local processing before sending the result to a central location, enabling a callout of medical staff should vital signs vary from threshold criteria.
- Most new cars today incorporate a car computer that links to monitors across engine components.
- Proximity-based services (such as Apple's iBeacon) enable retailers to track customer locations in stores.

In this model, local gateways take on a smarter role as the devices they connect to require higher levels of management and control — for example, involving software distribution, security configuration, and fault management. Sensor devices may be heterogeneous, particularly if deployments take place over long periods of time. For example, smart parking spaces across a city may take years to deploy. Gateways may therefore have to deploy the same programming code across multiple device types and versions.

Smart client: enabling peer to peer

In this model, local devices are sufficiently powerful to perform a variety of functions without requiring central intervention. A scalable backend can still be used for data storage and analysis, but control functions and information sharing take place locally.

Examples include:

- Smart grids, in which metering devices send information to a central point for analysis and interpretation and which can then be used to control flow of resources such as electricity or water.
- Smart cars, where the vehicle represents a local processing hub for everything within it, each element of which is a "thing." Consider BMW's use of its smart-car network to sense road conditions and distribute the information around the network of BMW drivers. While this model involves the centralized analysis of data, the overall effect is peer-to-peer sharing of road insights.

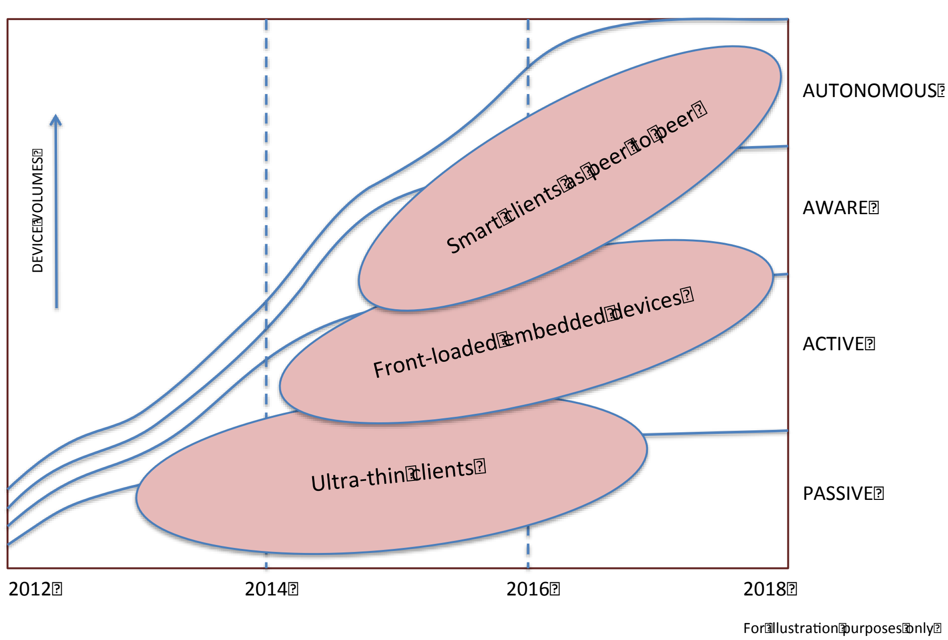
Moving from passive to autonomous

The level at which the three models apply depends on the amount of smartness required by the use case. In the previous Gigaom Research report, we defined four levels of smart: passive, active, aware, and autonomous. We can apply the above models to these levels of smart as follows:

- **Passive.** Ultra-thin clients
- **Active.** Ultra-thin or front-loaded clients
- **Aware.** Front-loaded preprocessing or smart clients
- **Autonomous.** Largely smart clients

While the volume of passive sensors may always be greater than active or aware controllers, it is to be expected that as an increasing number of smarter use cases come into play, the volumes of devices involved in higher-order use cases will increase over time, as shown in the figure below.

Evolution of IoT models



Source: Inter Orbis, Gigaom Research

Delivering IoT use cases

What do IoT configurations need in order to deliver successful IoT use cases? As we have already mentioned, real-time performance is not necessary in every scenario, even if it were possible. However, for the above models to work and for the architecture to meet the expectations set for it, a number of pieces need to be in place:

- **Event frequency.** A given use case may impose certain criteria on how often events need to be generated. Some use cases only require events to be collated once per day, or whenever a physical object (perhaps augmented by RFID or NFC) is in range of a sensor. Or it may be a requirement that events are collated every second or even more frequently. This requirement puts pressure on both sensors and gateway technologies.

  Event frequency can vary by use case. For example, in health care scenarios, vital signs such as heart rate need to be delivered in real time. For others, such as body mass index, once per day may be enough. In general, however, once set, such criteria need to be kept to. Some use cases — for example, fault monitoring — require only occasional generation of events, but when events do occur, they need to be transmitted without delay.

- **Responsiveness.** Analytics, management, and control systems also need to be able to deliver a response within an appropriate time frame. The first dependency is on network bandwidth: Latency can accumulate across device, gateway, mobile, and internet connections.

  In terms of delivering appropriate analytical capabilities, it is possible to turn big data capabilities such as Hadoop toward solving the needs of IoT, but such solutions currently tend to be custom-built rather than available as off-the-shelf solutions. Few solutions exist to support general-purpose management and integration (for example, from Bosch Software Innovations at one end of the scale and IFTTT at the other). No doubt this situation will change as more vendors and startups recognize the value of offering IoT-management solutions.

- **Reliability.** To fulfill the need for real-time responsiveness, IoT use cases require the service to be there when it is supposed to be. For example, for embedded devices handling health, safety, and other critical processes, even a 99.9 percent uptime SLA is unacceptable and may cause approvals to be withheld (for example, from the U.S. Food and Drug Administration with respect to health care devices).

While this criterion can make some potential use cases unachievable, reliability criteria can vary according to the type of event being collated. Non-critical events such as weather readings or footfall measurements may not require such stringent criteria as more-critical events. Equally, it may be preferable for a certain event to be received as quickly as possible. For example, it is still better to know that a theft has taken place an hour after the event than not to know at all.

- **Simplicity and interoperability.** Given the nature of IoT — that it involves the interconnection of everyday objects — each configuration needs to be simple to set up and use, whether in terms of plugging in and configuring devices, connecting with backend services, or generating results. The result should be adaptable to change, not least because IoT is still maturing and developing in scope.

  While it is early days for such standards, IoT conforms in principle and practice with the architectures already being developed for web services and mobile applications — for example, employing RESTful interfaces for the asynchronous transmission of data. At the same time, emerging approaches such as software-defined networking (SDN) and network functions virtualization (NFV) are also driving API-based approaches at the network level, further catalyzing interoperability.

- **Security and privacy.** The service must be able to protect the data it generates or collates, both at rest (on the device or in the cloud) and in transit across the network in terms of confidentiality, availability, and integrity. In addition, the service must respect the privacy of the people involved. For example, seemingly innocuous use cases such as cameras in cars could capture and record information that could then be used in unexpected ways, such as capturing an illicit liaison in the parking lot.

  Security is currently by no means a given. Many devices being considered as candidates for connection to backend services were designed to be stand-alone and therefore not with security in mind, as illustrated by security breaches in SCADA–based industrial control systems, such as the attack on a sewage control system in Queensland, Australia. Equally, current privacy protections have frequently been found lacking with regard to gathering personal information.

Clearly the market is moving mainstream, not simply in terms of having smart devices but also in terms of real-time responsiveness. But it's not there yet. Many tech companies are just now throwing their hats into the ring. For example, Salesforce.com only announced an IoT strategy at the end of Nov. 2013.

However, organizations such as Wind River and Aeris are coming out of the M2M space to offer a far broader range of foundational services to support IoT configurations.

Moving IoT forward in business

IoT enables businesses of all sizes to extend their sensory networks, resulting in a number of opportunities to become more efficient and effective in terms of how services are delivered. For organizations looking to get ahead, we offer the following guidance:

- **First extend, then enhance and direct your existing business.** IoT success stories have traditionally come from knowing where objects are located and being able to monitor equipment better. As sensor costs fall, consider where similar mechanisms might extend the reach of your business, enhance your ability to monitor operations, and provide additional insights, building on what you already have in place.

- **Look at existing success stories across industries.** Examples of successful use cases are already appearing in multiple sectors: remote health monitoring, improved food production, and theft protection. By looking for parallels in your industry and across adjacent industries, you can consider where similar models might apply to your own organization and assess whether the cost-benefit equation would deliver positive value to your own business.

- **Be prepared to brainstorm.** These are early days for IoT, and the most exciting use cases are likely still to be discovered. By running brainstorming sessions or hackathons or simply by looking around you and considering what might be connected, you could generate ideas that might be of great value to your business.

- **Choose the most appropriate architecture.** As we have seen, a number of models exist involving highly passive or more-active sensors, each of which imposes different constraints on the local gateway and backend technologies required. The selected architecture should take into account not only event collation, analysis, and interpretation requirements but also criteria such as security and manageability at each point in the architecture.

- **Run a pilot using the cloud first.** Start small and grow rather than trying to bite off too much. For example, fit a door with an open-close sensor or provide employees with devices to test. At the same time, keep in mind that IoT is about more than remote monitoring. Keep in mind how you might integrate with backend and enterprise systems. Even if the ultimate goal is to keep processing in-house, test ideas with cloud-based technologies first, both to manage the cost risks of a pilot and to provide sufficient headroom.

- **Involve the right people throughout.** Ensure that your organization is geared up — in terms of management strategy, processes, roles, and responsibilities — to make the most of any IoT solution. Otherwise it will simply become an isolated remote-monitoring application. Ensure you have the right people in the room early on, in particular production, line-of-business, and customer service managers whose business areas stand to benefit. Throughout piloting and subsequent deployment, be sure to keep focused on the goal of getting useful information to the right people.

IoT will catalyze the API economy, further creating and enhancing opportunities to meet new business scenarios. As well as basic examples, as this report shows, we are starting to see a number of next-generation use cases that use analytics, architecture, management, and security to deliver autonomous solutions that can benefit business, consumers, and citizens alike.

More-advanced examples incorporate a real-time feedback loop between collecting events and being able to take decisive action, with or without human intervention. It is this closed loop that will become fundamental to the future of IoT, creating a real-time sensory network to the benefit of organizations large and small.

Key takeaways

- While IoT builds on M2M and OT principles, its value-add is to provide a sensory capability enabling real-time analysis and response rather than simply remote monitoring and control.
- IoT use cases cannot be ends in themselves; they need to fit with how today's agile organizations are structured and managed and the way people work.
- In practical terms this means using IoT to extend the reach of the organization in ways that support smarter decision making and faster response to events, potentially in real time.
- Most use cases follow one of three architectures: ultra-thin, smart clients, or peer to peer. Each relies on different combinations of embedded sensors, gateway devices, processing, and analytics.
- These models lend themselves to similar development approaches to cloud-based services and mobile apps. The goal is fast delivery of value rather than the deployment of cumbersome infrastructure.
- A number of constraints exist on current use cases that set the bar for success. These include reliability and responsiveness, simplicity and interoperability, security, and privacy.
- Not all use cases need to be smart. Over the next few years we will see an evolution of IoT from more-passive to fully autonomous examples as the market matures and standards, protocols, analytical, and management capabilities develop.
- Organizations have the opportunity to extend and enhance existing business models using IoT. Now is the moment to brainstorm how this might take place, looking at emerging success stories and adjacent examples from similar industries.

About Jon Collins

Jon Collins is the principal adviser at Inter Orbis. With 25 years of background in the technology industry, Collins 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. He is the 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 Collins' varied career he has acted as an IT manager and software consultant, project manager, training manager, IT security expert, and industry analyst. Collins was named European analyst of the year by the Institute of Industry Analyst Relations in 2009.

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