WHITE PAPER

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The Evolution of the Internet of Things

Introduction

The Internet of Things (IoT) is rapidly evolving. There is a need to understand challenges in obtaining horizontal and vertical application balance and the key fundamentals required to attain the expected 50 billion connected devices in 2020.

With more than 27 years in the high tech industry, Jim Chase has spent his career working with customers and helping them get in front of technology trends and challenges. As a trusted expert, he employs his system solutions approach to business and consumer cases worldwide. It is that methodology that has him creating solutions at Texas Instruments (TI) for the IoT and helping customers connect their products.

From connected things to living in the data, preparing for challenges and IoT readiness

The Internet of Things (IoT) is generally thought of as connecting things to the Internet and using that connection to provide some kind of useful remote monitoring or control of those things. This definition of IoT is limited, and references only part of the IoT evolution. It is basically a rebranding of the existing Machine to Machine (M2M) market of today.

IoT in its culmination – where we live in the data is defined as:

> The IoT creates an intelligent, invisible network fabric that can be sensed, controlled and programmed. IoT-enabled products employ embedded technology that allows them to communicate, directly or indirectly, with each other or the Internet.

In the 1990s, Internet connectivity began to proliferate in enterprise and consumer markets, but was still limited in its use because of the low performance of the network interconnect. In the 2000s Internet connectivity became the norm for many applications and today is expected as part of many enterprise, industrial and consumer products to provide access to information. However, these devices are still primarily things on the Internet that require more human interaction and monitoring through apps and interfaces. The true promise of the IoT is just starting to be realized – when invisible technology operates behind the scenes dynamically responding to how we want "things" to act.

To date, the world has deployed about 5 billion "smart" connected things. Predictions say there will be 50 billion connected devices by 2020 and in our lifetime we will experience life with a trillion-node network. Those are really big numbers. How things are fundamentally deployed today is a barrier to realizing those numbers. The industry will only achieve the reality of 50 billion connected devices by simplifying how things connect and communicate today.

The IoT of tomorrow

The hotel where I have a reservation knows I am coming and the approximate time of my arrival because I have allowed Apple and Google to track my location. It also knows that I am hot and sweaty from my trip because of the temperature and moisture sensors that are part of my smartwatch. The hotel room I will stay in is currently dormant (no lights, drapes closed, the temperature is at optimized dormant levels). Upon my arrival, the valet knows it is me. He opens my door and the car adjusts the seat because it detects the valet. My preference is to carry my own bag, so I am not accosted by the bell captain. Once in proximity of the hotel lobby, a secure key app is available on my smartphone. By the time I reach the elevator, the room temp has adjusted to coincide with my smartwatch sensors. The light level, music and privacy settings are to my requirements. Because I am hot and sweaty the room also prepares hot water for a shower I will probably take after entering into the room. As I approach, the secure key app unlocks the room door. Once settled for the night, the room detects the lights are turned out, it changes the temperature setting to my sleep preferences.

In this scenario, every room in this particular hotel chain has multiple sensors and actuators. Every rental car has multiple sensors and actuators. I am wearing multiple sensors and actuators, like a watch vibration for alerts. I am not interacting with my smartphone touchscreen constantly to direct these connected things to take actions even though it is one gateway for my activity. There will be millions of people doing this every day. We will be living IN the data.

This vision of IoT will not happen right away. The scale required will only be achieved by creating a lowest common denominator, simple messaging scheme that everyone on the planet will agree to. It will have to be digitally organic, imitating nature. At present, technology protocols and data structures are limited by their design complexity as well as security, extensibility, and much more. Our connected devices will have to become easier to use even though the complexity of the devices will increase. The line between analog and digital will blur. Every person on the planet will be able to “author” his or her own life environment, even though they know basically nothing about the underlying technology.

The IoT of today

Manufacturers have been connecting things to the Internet before we called it the Internet. By the mid-1990s, Web servers were being added to embedded products. Current M2M manufacturers have been integrating Internet-connected systems into high-value asset tracking, alarm systems, fleet management and the like for more than 15 years. These M2M systems are challenging to build even though some are based on industry standard protocols. However, it is getting easier to integrate M2M systems as more powerful processors are incorporated into the end nodes. And since these processors support high-level operating systems (OSes) and languages, the platform can leverage intelligent frameworks. These systems are typically tied into high-end business service layers and are managed by a network operations center (NOC).

Consumers already have connected things like thermostats, energy meters, lighting control systems, music streaming and control systems, remote video streaming boxes, pool systems, and irrigation systems with more to come. Most of these systems have some connectivity through a Web site so that a user can manage them through a standard Web browser or a smartphone app, which acts as a personal NOC.

Figure 1. IoT-enabled home with connected devices and appliances working invisibly for consumers.

While both the industrial and consumer scenarios are exciting, deployment is not simplified since they are all disparate vertical systems. The systems may use the exact same protocols and OS underpinnings, but the communications layers are inconsistent. Each also uses open application programming interfaces (APIs) without a horizontal connection, which would lead to easier cross-application integration.

Take for example a sprinkler control system. It can have a level of intelligence so it knows when to water based on sensors and Internet weather data under programmable control. However, it does not know anything about motion sensors around a house that might indicate a reason to delay the zone to avoid drenching the dog or kids. There are no motion sensor inputs on the sprinkler controller, so other motion control vertical integration needs to be used to transfer data to another cloud server. Then the two cloud servers need to be "glued" together somehow. Hopefully, both system integrations allow for some small amount of additional control. However, hope is never a good word in electronic systems. An additional vertical application written in Perl, Python, PHP or another programming language on a server can program a connection that allows motion to delay the sprinkler zone (or other logic the user may want). This is not easy unless you are an expert and therefore will not lead to rapid deployment.

This need to connect vertical integrations has led to the formation of new web services like **IFTTT.com** (If This Then That) and **zAPIer.com** that allow a user to graphically glue disparate vertical systems together. However, this requires users to sign up for yet another service to find out if they have an API interface that meets the specific vertical integration needs. These platforms are set up to provide basic "recipes" such as "*IF* I get an email from my wife *THEN* send a text to my phone." It is assumed that greater flow control will

come later. Back to the previous example, assuming the sprinkler system has a delay control API, one can glue the recipe into place: *IF* motion, *THEN* delay the sprinklers. That is three different services, three sign-ins (which will also have to be managed inside the third service), three different smartphone apps and several points of failure. Now, what if the user wants to integrate this recipe with his or her calendar so the yard is dry for an outdoor family gathering? The scenario becomes more complicated.

While the applications discussed above are interesting, they also do not lead to rapid IoT deployment. Sure, there will be an uptick in the maker communities as well as some new vertical applications and carrier additions. But the IoT is not about simple vertical one-off texts or tweets. That creates interesting demos, but it lacks scalability and integration across vertical systems. The IoT should enable notifications, but it also needs a simple way for devices to run programs and respond to other devices or services to create a sophisticated application without using a complex programming environment.

The IoT: Vertical and horizontal balance

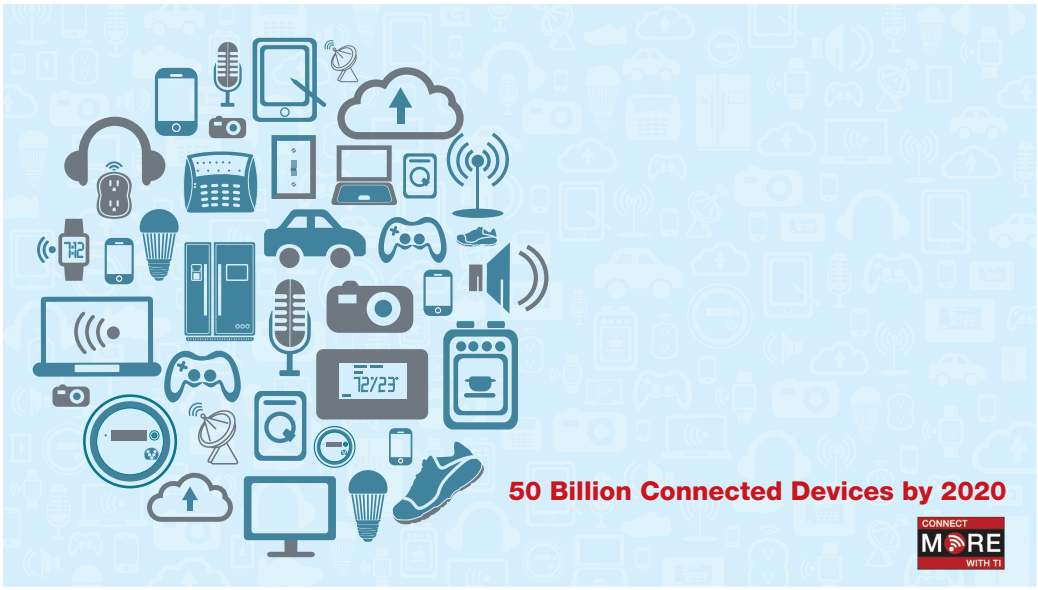
It is hard to argue that the Internet as we know it today (technically HTTP) was born of altruistic intent by Tim Berners-Lee to connect everyone around the world with an open platform. Prior, there were only proprietary enterprise networks with little to no sharing of information – the verticals of the pre-Internet days. ARPANET put some basic plumbing and "messaging" protocols in place to get the party started. The architecture was robust and the vertical spin-offs became the Defense Data Network (DDN) and the National Science Foundation Network (NFSNET). Through public and private industry funding, NFSNET eventually became a major part of the Internet backbone. In the Internet of today there are vertical applications on a fundamentally basic platform of connectivity and information passing.

Today, manufacturers have a multitude of vertical application requirements. Some may be altruistic, but most have money behind their requirements. Without that, there would be no next steps. However, there will be an altruistic requirement to gain horizontal balance. The IoT of tomorrow will be the largest horizontal system architecture ever created. Vertical applications will continue to exist; however, the fundamental lowest levels of connectivity and information passing will need to be ubiquitous and invisible in all applications.

Additionally, horizontal balance will require the IoT to look more like an organic system. When cells replicate, they pass fundamental information from one cell to another in the form of DNA. Cells combine to form a hierarchy of automatic mechanisms that use a nervous system to build and protect its cellular architecture – the body's form of horizontal integration. A human has trillions of cells that are very resilient and can work for 100+ years without a "reboot." It is no wonder why organic systems are being studied as a basis for fundamental information and device architecture.

One also might conclude that the Internet has the characteristics of an organic system. However, the Internet of today has most of its traffic aggregated into a few very large data pipes. The original Internet was a much "flatter" looking entity and more peer-to-peer in nature. Bandwidth requirements were fairly low with the largest consumer of bandwidth being simple messaging traffic. Media- and time-critical data forced the

emergence of big pipes. Client-server architecture is dominant today, primarily driven by content aggregators and big pipe companies. As the industry progresses there will be a gradual shift back to the original flatter architecture. Fat pipes will not go away as heavy bandwidth and time-critical requirements will still exist. However, when trillions of connected devices exist in the IoT, there will be numerous paths for data flow. The aggregate bandwidth of this massive peer-to-peer platform will far exceed the performance of the fat pipes. Since there will be no way to regulate the network, it will become completely neutral and basically invisible. Our great grandchildren will not even know what an "Internet connection" was. That assumes, of course, that we eventually all agree on the fundamental "currency" of the IoT.



Getting IoT ready

Preparing the lowest layers of technology for the horizontal nature of the IoT requires manufacturers to deliver on the most fundamental challenges, including:

- **Connectivity:** There will not be one connectivity standard that "wins" over the others. There will be a wide variety of wired and wireless standards as well as proprietary implementations used to connect the things in the IoT. The challenge is getting the connectivity standards to talk to one another with one common worldwide data currency.
- **Power management:** More things within the IoT will be battery powered or use energy harvesting to be more portable and self-sustaining. Line-powered equipment will need to be more energy efficient. The challenge is making it easy to add power management to these devices and equipment. Wireless charging will incorporate connectivity with charge management.
- **Security:** With the amount of data being sent within the IoT, security is a must. Built-in hardware security and use of existing connectivity security protocols is essential to secure the IoT. Another challenge is simply educating consumers to use the security that is integrated into their devices.

- **Complexity:** Manufacturers are looking to add connectivity to devices and equipment that has never been connected before to become part of the IoT. Ease of design and development is essential to get more things connected especially when typical RF programming is complex. Additionally, the average consumer needs to be able to set-up and use their devices without a technical background.
- **Rapid evolution:** The IoT is constantly changing and evolving. More devices are being added everyday and the industry is still in its naissance. The challenge facing the industry is the unknown. Unknown devices. Unknown applications. Unknown use cases. Given this, there needs to be flexibility in all facets of development. Processors and microcontrollers that range from 16–1500 MHz to address the full spectrum of applications from a microcontroller (MCU) in a small, energy-harvested wireless sensor node to high-performance, multi-core processors for IoT infrastructure. A wide variety of wired and wireless connectivity technologies are needed to meet the various needs of the market. Last, a wide selection of sensors, mixed-signal and power-management technologies are required to provide the user interface to the IoT and energy-friendly designs.

Summary

The IoT is expected to transform how we live, work and play. From factory automation and automotive connectivity to wearable body sensors and home appliances, the IoT is set to touch every facet of our lives. We will "author" our life with networks around us that constantly change and evolve based on our surroundings and inputs from other systems. It will make our lives safer with cars that sense each other to avoid accidents. It will make our lives more green with lighting systems that adjust based on the amount of daylight from windows. It will make our lives healthier with wearables that can detect heart attacks and strokes before they happen. There is a long road ahead to the IoT of 2020. But one thing is for sure, it is going to be amazing.

Texas Instruments and the IoT

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