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How big is the Internet of Things?

Technology evolution, market adoption, and the need for a horizontal IoT platform

Strategic White Paper

This white paper combines real market data with established information and communications technology (ICT) industry principles and high-tech marketing models to estimate the long-term value of the Internet of Things (IoT). It also explores the business rationale for implementing a standards-based, horizontal platform that will fuel the growth of the IoT by enabling a broad variety of devices and applications to share common functions and data.

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Introduction

The emergence of the Internet of Things (IoT) represents an unprecedented opportunity for many players in the communications, IT, and consumer electronics industries. Although IoT definitions, application scopes, and growth forecasts diverge significantly – for example, analysts estimate that there will be anywhere from 20–100 billion connected devices by 2020 – everyone agrees that the IoT will be huge. Estimates regarding the economic impact of the IoT reflect this consensus view. For example, IDC expects global IoT spending to reach nearly US$1.29 trillion over the next three years.[1] McKinsey believes that the market for IoT could reach US$11.1 trillion by 2025.[2]

This white paper uses real market data to measure the tangible and intangible value of the IoT, and estimate of its long-term value. Starting from two established information and communications technology (ICT) industry principles – Moore's law and Metcalfe's law – it explores the IoT's evolution curve relative to performance, cost, and value.

Introducing Geoffrey Moore's chasm theory, and Jeremy Rifkin's zero marginal cost model, the paper takes a deeper look at the IoT's challenges and opportunities, as well as its social and economic potential.

The paper then analyzes the hypothesis in quantitative terms. Applying numbers to the hypothesis yields insights into why IoT-related estimates are so lofty, and how the theorems will interact to enable a revolution in the way people go about their daily activities.

Finally, the paper explains the business rationale for a standards-based, horizontal approach to the IoT. It concludes that the deployment of a common network and platform infrastructure, on which a broad variety of devices and applications share common functions and data, will fuel the exponential growth of the IoT.

Moore's law has been driving IoT evolution

In 1965, Intel co-founder Gordon Moore predicted that the transistor density (and thus performance) of microprocessors would double every two years. Take, for example, the iPhone 7, which is 4 times faster, has 8 times more RAM memory, and costs 40 percent less (on contract) than its first-generation counterpart from ten years ago.[3]

The notion of doubling every two years suggests a parabola-shaped curve, but Moore's growth function is almost always represented in a straight line and complemented by a logarithmic scale on the Y-axis, as shown in Figure 1.

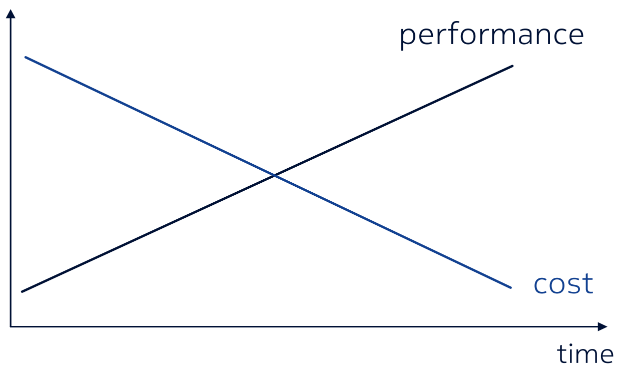

Figure 1. Moore's law

[1] "Worldwide Semiannual Internet of Things Spending Guide", IDC, 2017

[2] "Unlocking the potential of the Internet of Things", McKinsey Global Institute, 2015

[3] "Comparing the original iPhone to the iPhones 6 and 6 Plus", newatlas.com, 2015

Although recent articles[4] and chip-maker announcements[5] suggest that the evolution of silicon technology may be reaching its physical limit, Moore's prediction has been driving ICT evolution for the past five decades (Figure 2).

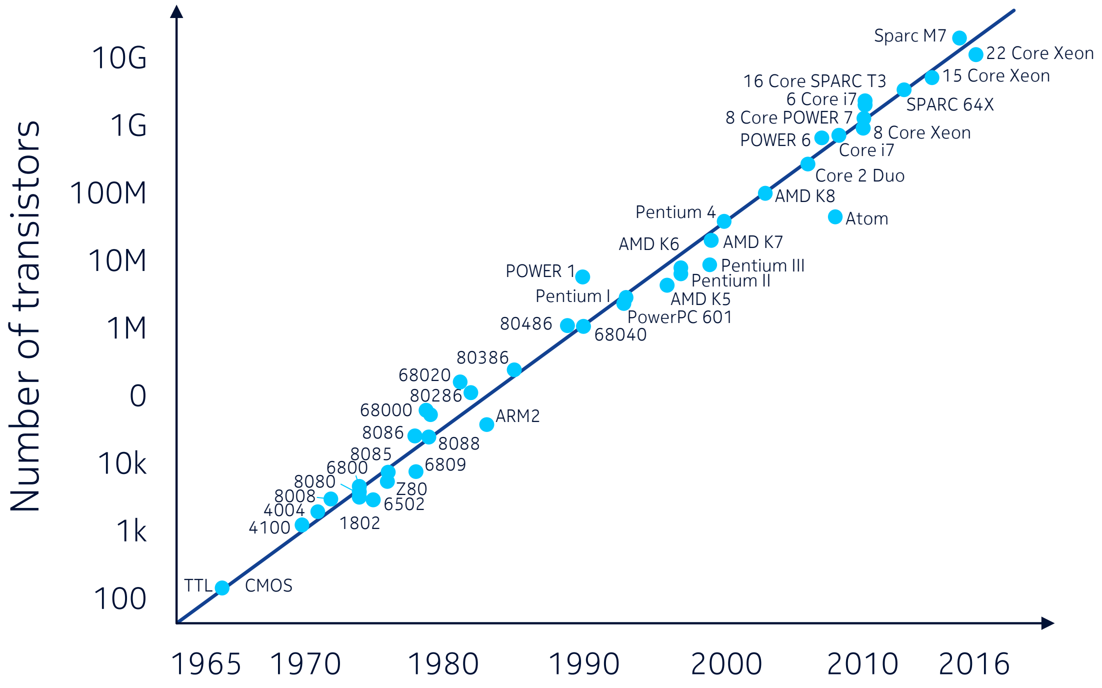

Figure 2. Processor evolution is following Moore's law

Interviewed by the New York Times[6] on the 50th anniversary of the law named after him, Gordon Moore admitted his amazement about the preciseness of his 1965 forecast:

> The original prediction was to look at 10 years, which I thought was a stretch. This was going from about 60 elements on an integrated circuit to 60,000 – a thousand-fold extrapolation over 10 years. I thought that was pretty wild. The fact that something similar is going on for 50 years is truly amazing. You know, there were all kinds of barriers we could always see that [were] going to prevent taking the next step, and somehow or other, as we got closer, the engineers had figured out ways around these. But someday it has to stop. No exponential like this goes on forever.

Mobile devices and machine-to-machine (M2M) communication modules are following similar performance and cost curves. According to Machina Research, narrowband IoT (NB-IoT) efforts will result in sub-ten-dollar "Category Zero" LTE modules by 2018. It should be noted, however, that the total cost of ownership (TCO) of M2M connectivity depends on more than just the hardware module element, which represents only about 15 percent of the cost. TCO also includes design, integration, and device–network certification costs.

[4] "The chips are down for Moore's law", nature.com, 2016

[5] "Intel's 2016 Chip Line-Up Will Put Moore's Law on Hold", gizmodo.com, 2015

[6] "Moore's Law Turns 50", the New York Times, 2015

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Metcalfe’s law adds value to the equation

Several years after Gordon Moore’s famous observation, another technology pioneer, 3Com co-founder Bob Metcalfe, stated that the value of a network grows by the square of the number of network nodes (or devices, or applications, or users), while costs follow a more or less linear function (Figure 3). For example, consider a wireless network. If the network connects just two mobile devices, the devices can only communicate with each other. However, if the network connects billions of devices and applications, opportunities for communication rise dramatically.

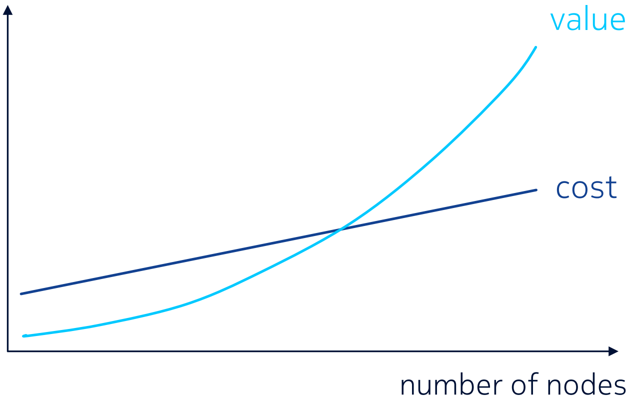

Figure 3. Metcalfe’s law

Metcalfe’s law is about network growth, value creation, and customer acquisition rather than technological innovation. The revenue growth of Facebook provides a good example of the law. It has been following an almost perfect Metcalfe trajectory, as shown in Figure 4.

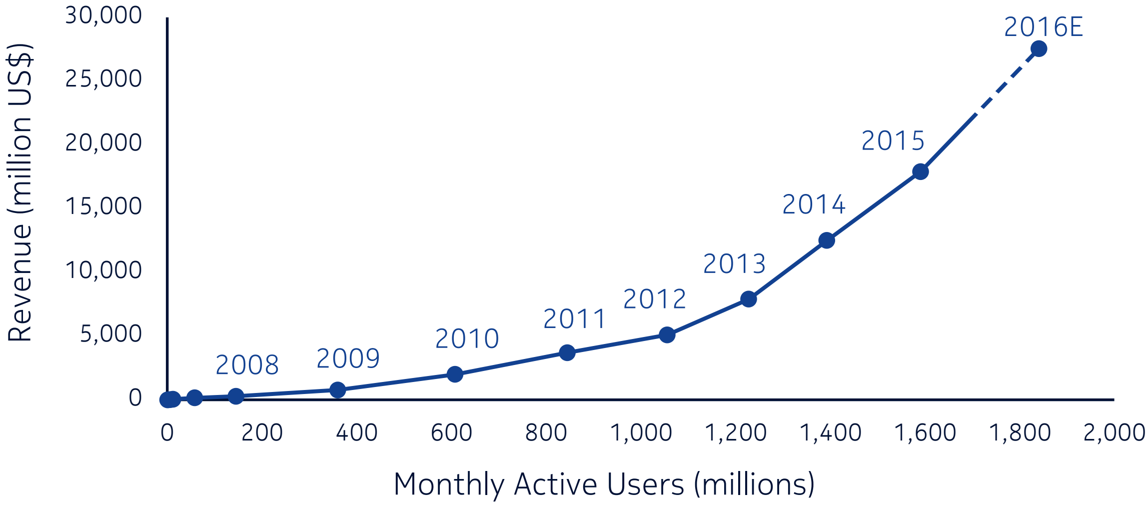

Figure 4. Facebook growth is following Metcalfe’s law

The combination of Moore’s and Metcalfe’s laws explains the evolution of communication networks and services, as well as the rise of the IoT. Current IoT growth is enabled by hardware miniaturization, decreasing sensor costs, and ubiquitous wireless access. These capabilities are fueling a rapid increase in the use of smart devices and applications. Current predictions show a compound annual growth rate (CAGR) of more than 50 percent for the next five years.

Unfortunately, general availability of state-of-the-art technology is not always a recipe for success. Some of the designated "killer" IoT devices and apps are still struggling for broad user adoption – particularly in the consumer domain, where smart watches and connected thermostats are notorious examples (Figure 5).

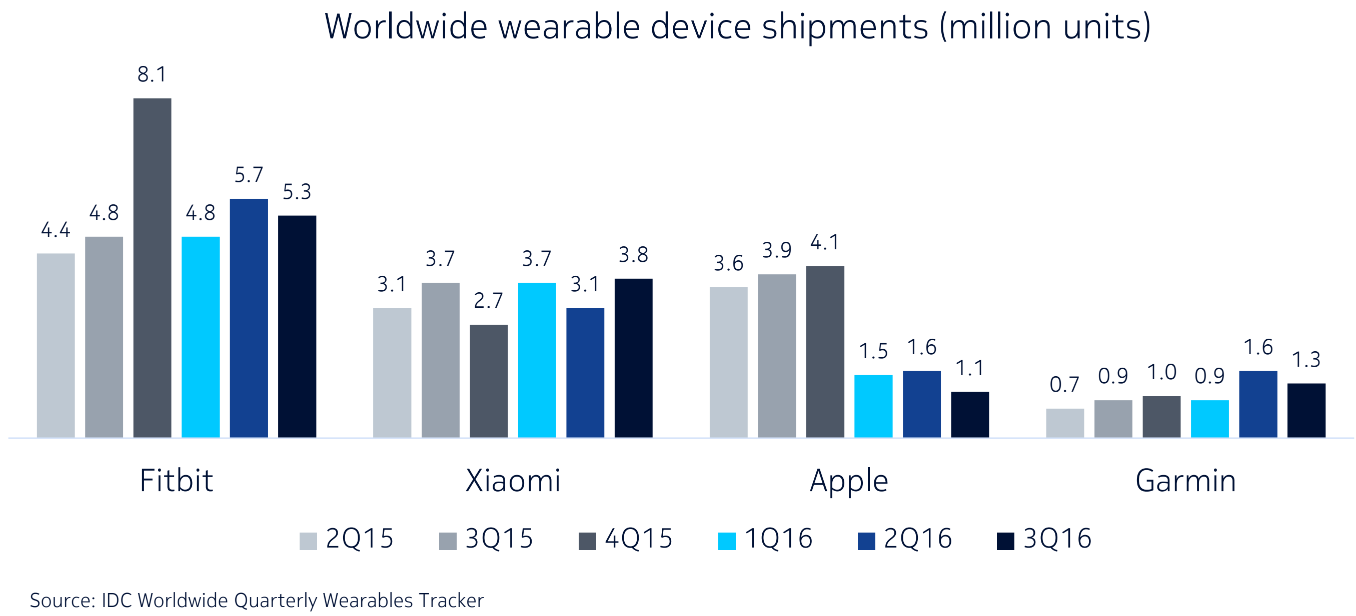

Figure 5. Worldwide shipments by the top four wearable device vendors (in millions of units)[7]

Crossing the chasm

A look at the technology adoption lifecycle helps explain the slow take-up of connected devices. Deeper insights can be gained by considering the "chasm theory" that management consultant Geoffrey Moore developed based on Everett Rogers' Diffusion of Innovations curve.[8]

In his book **Crossing the Chasm: Marketing and Selling High-Tech Products to Mainstream Customers**, Moore writes about the gap, or chasm, that product marketers have to bridge to inspire take-up of new technology by early enthusiasts and achieve mass market adoption (Figure 6).[9]

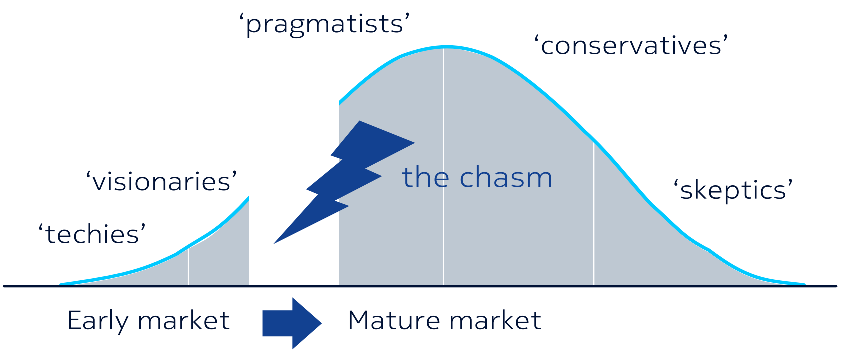

Figure 6. Technology adoption curve showing the chasm

[7] "Worldwide Quarterly Wearables Tracker", IDC, 2016

[8] Diffusion of Innovations, Everett M. Rogers, Free Press of Glencoe, 1962

According to Moore, early adopters are technology enthusiasts looking for a radical shift, while the early majority want a productivity improvement.

> What the early adopter is buying, is some kind of change agent. By being the first to implement this change in their industry, the early adopters expect to get a jump on the competition, whether from lower product costs, faster time to market, more complete customer service, or some other comparable business advantage. They expect a radical discontinuity between the old ways and the new, and they are prepared to champion this cause against entrenched resistance. Being the first, they also are prepared to bear with the inevitable bugs and glitches that accompany any innovation just coming to market.
>
> By contrast, the early majority want to buy a productivity improvement for existing operations. They are looking to minimize the discontinuity with the old ways. They want evolution, not revolution. They want technology to enhance, not overthrow, the established ways of doing business. And above all, they do not want to debug somebody else's product. By the time they adopt it, they want it to work properly and to integrate appropriately with their existing technology base.[9]

But there's more to the chasm than consumers being slow (or conservative) in adopting new technologies, products, and services. As Clayton Christensen suggests in The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail, successful companies put too much emphasis on customers' current needs, and fail to adopt new technology or business models that will meet their customers' unstated or future needs.[10] In other words, great companies need to deliver disruptive products and services. For example, the iPhone was a disruptive product, but the Apple Watch wasn't.

A shift is happening within the chasm

Figure 7 combines the preceding charts and includes some visual manipulation with axes, scales, and representations. It shows that the chasm is the point where the shift from a technology-driven model to a value- and customer experience-driven business needs to take place (Figure 7). If this shift doesn't happen, new product or technology introductions are doomed to fail.

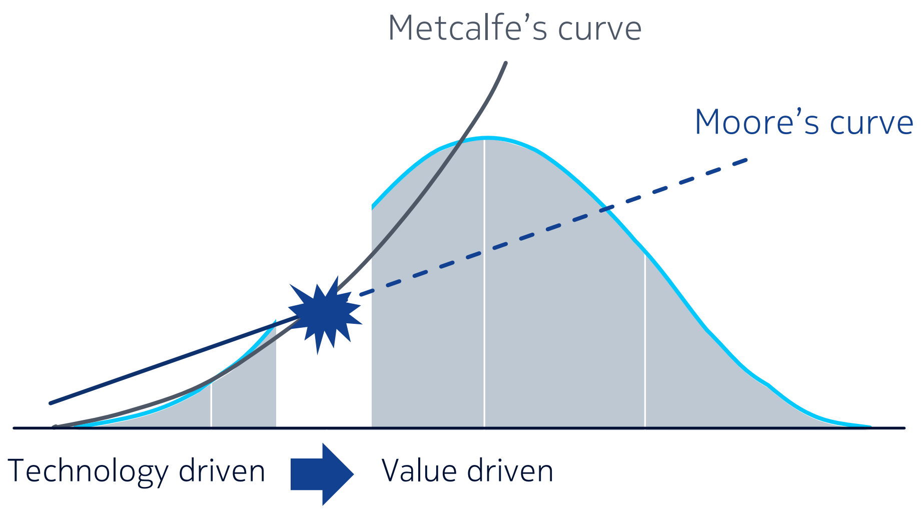

Figure 7. The tipping point of technology and value

[9] Crossing the Chasm: Marketing and Selling High-Tech Products to Mainstream Customers, Geoffrey A. Moore, Harper Business Essentials, 1991

[10] The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail, Clayton Christensen, Harvard Business Review Press, 1997

In a more recent article, “The Nature of the Firm – 75 Years Later,”[11] Geoffrey Moore writes:

> Smartphones and tablets are reengineering whole swaths of the consumer economy, from information access (Google) to communication (Facebook and Twitter) to media and entertainment (YouTube) to transportation (Uber) to hospitality (Airbnb) to dining (OpenTable and Yelp), and beyond.... At the same time, the big data analytics and cloud computing that enabled consumer IT to scale are now also being coopted by enterprises to help them scale their reach and increase their efficiency and effectiveness....
>
> Not surprisingly, transaction costs decrease – dramatically! All the overhead, all the delays, all the errors, all the confusion created by complex systems and well-intentioned but imperfectly informed human beings – all that sludge is being flushed from the system... as transaction costs decrease, the value of services relative to products increases. That is because one of the key selling points of a product is that it eliminates future transaction costs once it has been purchased.

Towards zero marginal cost and infinite value

In **The Zero Marginal Cost Society**, American social-economic theorist and activist Jeremy Rifkin describes how new technologies such as 3D printing, green energy, and the IoT are quickly moving us to an era of nearly free goods and services (and, according to the author, the eclipse of capitalism).[12]

> Billions of sensors are being attached to natural resources, production lines, the electricity grid, logistics networks, recycling flows, and implanted in homes, offices, stores, vehicles, and even human beings, feeding Big Data into an IoT global neural network. Prosumers can connect to the network and use Big Data, analytics, and algorithms to accelerate efficiency, dramatically increase productivity, and lower the marginal cost of producing and sharing a wide range of products and services to near zero, just like they now do with information goods.

The programmable world will have an immense impact on many industries. In the logistics and transport sector, for example, access to real-time data on the location of goods, current weather conditions, traffic flows, and warehouse inventories and capacities will dramatically reduce the marginal cost of producing, storing, and delivering goods.

At the same time, the convenience provided by IoT technologies will add tremendous value for a lot of companies and consumers because it will boost productivity, increase efficiency, and improve the end-customer experience. As such, it is fair to say that the long-term value of IoT is nearly infinite.

Calculating the long-term value of the IoT

Moore’s law is a useful tool for estimating the long-term cost and performance of the IoT. It is typically calculated as the number of components per integrated function in an electronic circuit. The theory states that the number of components per given functionality in an integrated circuit doubles every two years. This translates in several ways: Circuits can become faster at a fixed size, smaller at a fixed speed, or cheaper at a fixed speed and size. These three factors can also be combined in infinite ways. The end product is optimized based on its intended use.

[11] “The Nature of the Firm – 75 Years Later”, bbvaopenmind.com, 2015

[12] The Zero Marginal Cost Society: The Internet of Things, the Collaborative Commons, and the Eclipse of Capitalism, Jeremy Rifkin, Palgrave Macmillan, 2014

Figure 8 presents a Moore's law curve that shows the density and cost evolution of devices between 2013 and 2020 in billions of components per function. The full curve starts in 1971, with the Intel 4004, which had no more than 2,300 transistors per CPU.[13] Compare this to the current generation of processors, like the Oracle Sparc M7, which has 10 billion transistors on board.[14] The curve extrapolates evolution to 2021.

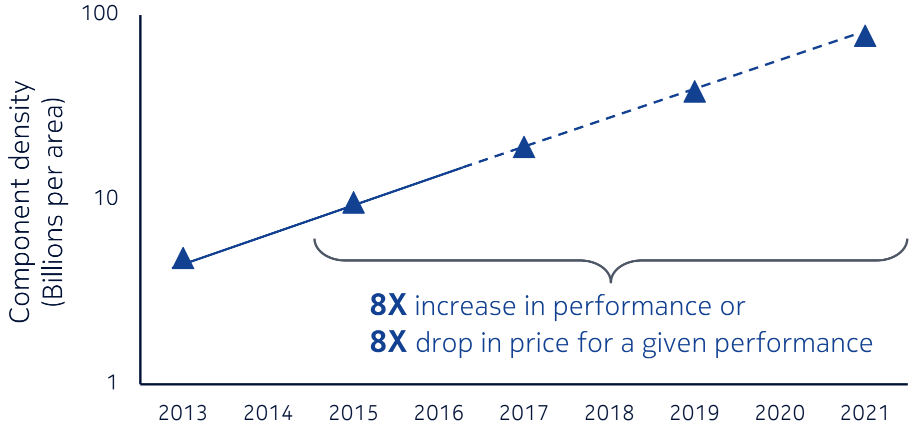

Figure 8. Moore's law for the IoT

Between 2015 and 2021, the performance of electronic circuits will increase by a factor of eight. This means that the cost of a fixed function will decrease by a factor of eight. Sensors will become much less expensive and smaller, and operators will be able to deploy them widely at low cost. The data collected by these sensors will be transmitted more cost effectively, and analytics computing power will be applied more quickly and cost effectively.

Figure 9 seeks to quantify Metcalfe's law and show the potential of the IoT by comparing the implied value of internet users and IoT devices. It plots the number of internet users from 2013–2020 based on actual statistics from 2000-2016[15] and projections for 2020.[16] It also plots the number of connected "things"[17] and their respective squared values based on conservative estimates of 21 billion connected things by 2020. Some projections go as high as 100 billion things, but these numbers would possibly exaggerate the value of IoT. Finally, the figure plots the "value" of the internet and the IoT based on Metcalfe's theory, with 2013 as the baseline.

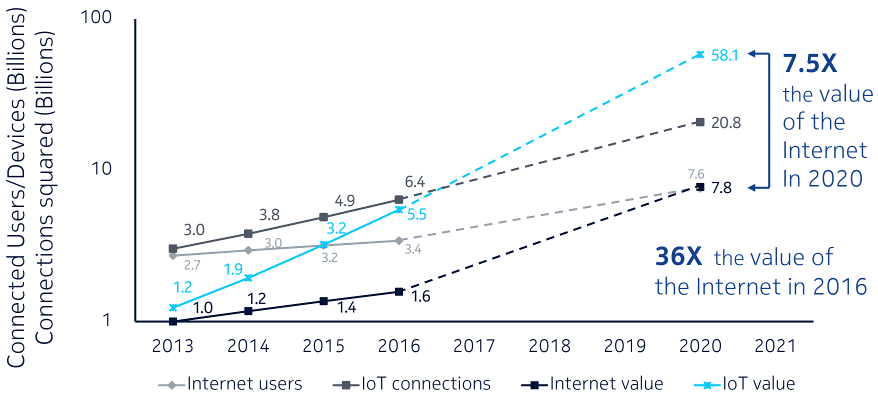

Figure 9. Metcalfe's law for the IoT

[13] "Moore's Law at 50: Its past and its future", extremetech.com, 2015

[14] "Oracle debuts first systems with 10-billion-transistor SPARC M7 chip", siliconangle.com, 2015

[15] "Internet users in the world", internetlivestats.com, 2016

[16] "Global internet users to reach 7.6 billion within the next 5 years", broadbandchoices.co.uk, 2014

[17] "6.4 Billion Connected 'Things' Will be in Use in 2016, Up 30 Percent from 2015", Gartner, 2015

The extrapolation in Figure 9 indicates that, based on the number of connections, the IoT may have 7.5 times more value than the internet by 2020. It also indicates that the IoT will have about 36 times more value than today's internet, assuming the node values are more or less equal.

As the number of devices connected through IoT increases due to Moore's law, and subsequently drives down the cost of the technology required, the value of the IoT will accelerate. With costs dropping and value increasing exponentially, new business models become viable and sustainable.

This is the tipping point at which the IoT moves from being an impressive technical feat to an actual business, or in other words "crosses the chasm" as challenged by Geoffrey Moore. The acceleration of value continues because the IoT can now be used to reduce marginal transaction costs and push inefficiencies out of the system.

A standards-based horizontal IoT platform fuels exponential growth

Many of the early IoT applications came – and still come – to market following a vertical model in which each solution was implemented on separate infrastructure. Each implementation requires a new or tailored IT development effort, and uses a separate management and execution platform. This siloed approach has an impact on development, deployment, and operating costs. It also constrains opportunities to realize meaningful economies of scale, develop solutions that can apply to more than one vertical market, and benefit from application interworking and data sharing – all of which are needed to make the IoT happen.

The IoT industry can break free of silos by evolving to a technology platform, on the network and software sides, that is reusable across different applications and that implements an "any device, any network, any application" model. The only way to achieve such a model is by standardizing protocols, functions, and interfaces.

At first sight, IoT is all about vertical solutions that beg for a vertical model. However, there is a clear business rationale for a horizontal platform with a common set of service capabilities, standardized interfaces, and open application programming interfaces (APIs) that enable faster growth and innovation. With a horizontal IoT platform, application developers, device manufacturers, and service providers will be able to use common infrastructure and share platform functions and data.[18]

A horizontal IoT platform will also boost the network's value as defined by Metcalfe's law. Figure 10 shows an example configuration in which N different vertical applications (A_i) are deployed on N different "stovepipe" platforms (P_i) with M connected devices (D_{ij}) each. With this configuration, the discrete y-value of Metcalfe's curve is equal to $N^*(M+1)^2$.

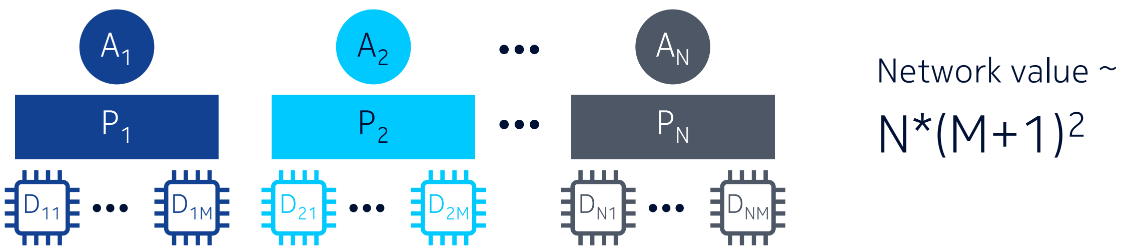

Figure 10: Metcalfe's law for N vertical applications

[18] "The importance of standards in making the Internet of Things happen", ETSI/oneM2M, 2016

A common, horizontal platform like that shown in Figure 11 connects all N applications to all N*M devices. This causes the network value to grow exponentially, to $(N*(M+1))^2$.

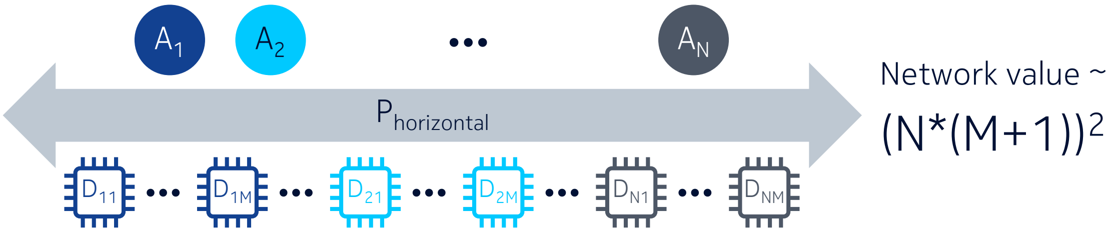

Figure 11: Metcalfe's law for N applications on a horizontal platform

A horizontal platform with open interfaces and standardized protocols will also allow IoT service providers to reduce investments, lower operational expenses, scale faster, speed up time to market, facilitate partnerships, and deliver a better customer experience. Device vendors and application developers will be able to concentrate on their real differentiators, rather than on re-implementing the common functions provided by the platform.

A concrete use case helps illustrate the value of a horizontal IoT platform. Growth, synergies, and economies of scale are of utmost importance for the development of smart cities, in which many different devices and applications come together. A horizontal IoT platform infrastructure makes a lot of sense for a smart city implementation because it can be shared by a broad range of vertical stakeholders and solutions. These solutions can include road congestion monitoring, CCTV video analytics, smart traffic lights, smart lighting, smart parking, connected bus shelters, and carbon emission measurement

Consider the possibilities that arise if all these applications could benefit from each other's presence and data. For example, what if smart traffic lights had access to real-time information from video cameras and connected cars? Or public transportation authorities could adapt bus routes, schedules, and tariffs based on traffic congestion and environmental conditions?

Conclusion

Moore's and Metcalfe's laws will drive the chasm crossing that product marketers need to achieve to inspire early take-up and mass adoption of IoT technology. In doing so, they will increase the value of the IoT and accelerate the shift toward a zero marginal cost society and a programmable world where dynamic systems adjust and optimize on their own. This world will become a reality when sensing, connecting, and computing costs no longer prohibit ubiquitous deployment, and when horizontal IoT infrastructure, such as the Nokia IMPACT platform,[19] helps maximize synergies between devices, data records, and applications.

Understanding in qualitative and quantitative terms how the confluence of these factors drives IoT makes it easy to see why many predict that the value of the IoT will reach the trillions of dollars.

[19] "Nokia launches new IMPACT platform for fast and secure delivery of IoT services", Nokia, 2016

Abbreviations

API	application programming interface
CAGR	compound annual growth rate
CCTV	closed circuit television
ICT	information and communications technology
IoT	Internet of Things
M2M	machine-to-machine
NB-IoT	narrowband IoT
TCO	total cost of ownership

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