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Conference Paper

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2015 Regional Conference of the International Telecommunications Society (ITS): "The Intelligent World: Realizing Hopes, Overcoming Challenges", Los Angeles, USA, 25th-28th October, 2015

Provided in Cooperation with:

International Telecommunications Society (ITS)

Suggested Citation: van den Dam, Rob (2015) : Internet of things and its future, 2015 Regional Conference of the International Telecommunications Society (ITS): "The Intelligent World: Realizing Hopes, Overcoming Challenges", Los Angeles, USA, 25th-28th October, 2015, International Telecommunications Society (ITS), Calgary

This Version is available at:

<https://hdl.handle.net/10419/146311>

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Internet of Things and its future

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Abstract

IBM Internet of Things (IoT) research focuses on three components to address the multiple challenges of a scalable, secure and efficient IoT: Technology strategy, business and economic insights, and product and user experience design. By merging these three streams of research, IBM developed a tangible vision of the connected future and findings that can guide executives in making strategic IoT decisions and investments. As the IoT scales exponentially, decentralized networks have the potential to reduce infrastructure and maintenance costs to manufacturers. Decentralization also promise increased robustness by removing single points of failure that could exists in traditional centralized networks. By shifting the power in the network from the center to the edges, devices gain greater autonomy and can become points of transactions and economic value creation for owners and users.

Keywords: Internet of Things, ecosystems, Economy of Thing, big data, security

1. Introduction

More than a billion intelligent, connected devices already comprise today's "Internet of Things (IoT)." The expected proliferation of hundreds of billions more places us at the threshold of a transformation sweeping across the electronics industry and many others. Yet, the dream of a smart, safe and efficient future is threatened by subscription fees, ubiquitous advertising and intrusive surveillance. For the IoT to survive the end of trust and successfully scale from billions to hundreds of billions of devices, executives need to rethink the technology strategy, business models and design principles at its foundation. This paper shows that a low-cost, private-by-design "democracy of devices" will emerge that will enable new digital economies and create new value, while offering consumers and enterprises fundamentally better products and user experiences.

2. Why the IoT already needs a reboot

The rise of inexpensive general purpose computing has been accompanied by the availability of inexpensive sensors and actuators that today are cheap enough to embed in a device even if they are not used. Tremendous advances in cloud computing enable storage and analytics of the vast amounts of data generated by these sensors. Fueled by ubiquitous connectivity and the availability of billions of IP addresses with IPv6, the number of connected devices is forecasted to surpass 25 billion in 2020, up from 2.5 billion in 2009 and 10 billion today.

Looking forward, an increase in open web-service application program interfaces (APIs) will allow devices to connect and work smoothly as part of complex, multi-vendor networks. 3D printing and digital manufacturing will enable manufacturers to build and deploy devices in small batches, quickly pioneering new products and solutions.

The result: a proliferation of hundreds of billions of devices that will be no more expensive than their dumb counterparts, yet able to operate and act as part of complex, integrated systems. As with prior revolutions, this one will usher in another order-of-magnitude reduction in cost, as smartphones and tablets that range from US\$200 to US\$600 are supplemented by smart devices, such as doorknobs and light bulbs, that cost as little as US\$20.

So far, the first wave of the IoT has focused on very high-value applications. There have been visible successes in continuous monitoring of jet engines, automated smart meters and remote healthcare management. But demand has been slow to take off in many areas: only 30 percent of heavy industrial equipment is networked and only 10 percent of smart TVs are used for Internet viewing. Perhaps the slowest area of adoption is home automation, where consumers have failed to embrace devices from smart toothbrushes to refrigerators.

Market expectations and valuations, however, have been enormous – as much as 10 to 20 times revenue, even though revenues have been relatively small, particularly in the consumer space. This is largely a result of the cost and complexity of most IoT solutions, as well as enterprises and entrepreneurs treating the IoT as if it were just another computing platform, and applying the same set of business models: services, ecosystems, applications and analytics. Unless executives make big strategic changes, they are set to be disappointed as they seek to scale today's IoT solutions to support tomorrow's hundreds of billions of things (see Figure 1).

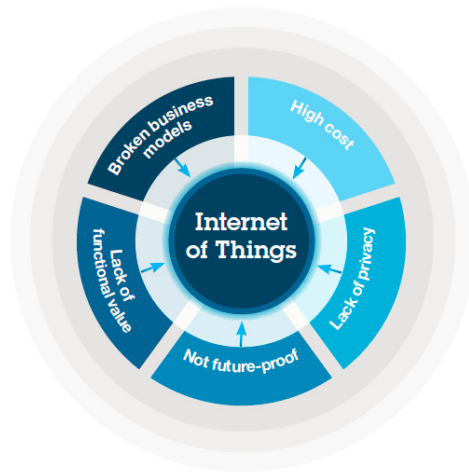


Fig. 1. Why today's Internet of billions of Things won't scale to the Internet of hundreds of billions of Things

Challenge one: The cost of connectivity

Even as revenues fail to meet expectations, costs are prohibitively high. Many existing IoT solutions are expensive because of the high infrastructure and maintenance costs associated with centralized clouds and large server farms, in addition to the service costs of middlemen.

There is also a mismatch in supplier and customer expectations. Historically, costs and revenues in the IT industry have been nicely aligned. Though mainframes lasted for many years, they were sold with enterprise support agreements. PCs and smartphones have not historically been sold with such profitable support plans; but with their shorter product life cycles, that has not been a huge problem.

With the IoT, it is unlikely that there will be enough margin for companies to cover several years of support and maintenance. The cost of supporting and serving billions of smart devices will be substantial – even something as simple as maintaining centralized servers that distribute regular software updates.

Challenge two: The Internet after trust

The Internet was originally built on trust. In the post-Snowden era, it is evident that trust in the Internet is over. The notion of IoT solutions built as centralized systems with trusted partners is now something of a fantasy. Most solutions today provide the ability for centralized authorities, whether governments, manufacturers or service providers to gain unauthorized access to and control devices by collecting and analyzing user data.

In a network of the scale of the IoT, trust can be very hard to engineer and expensive, if not impossible, to guarantee. For widespread adoption of the ever-expanding IoT, however, privacy and anonymity must be integrated into its design by giving users control of their own privacy.

Current security models based on closed source approaches (often described as “security through obscurity”) are obsolete and must be replaced by a newer approach – security through transparency. For this, a shift to open source is required. And while open source systems may still be vulnerable to accidents and exploitable weaknesses, they are less susceptible to government and other targeted intrusion, for which home automation, connected cars and the plethora of other connected devices present plenty of opportunities.

Challenge three: Not future-proof

While many companies are quick to enter the market for smart, connected devices, they have yet to discover that it is very hard to exit. While consumers replace smartphones and PCs every 18 to 36 months, the expectation is for door locks, LED bulbs and other basic pieces of infrastructure to last for years, even decades, without needing replacement.

An average car, for example, stays on the road for 10 years, the average U.S. home is 39 years old and the expected lifecycles of road, rail and air transport systems is over 50 years. A door lock with a security bug would be a catastrophe for a warehousing company and the reputation of the manufacturer. In the IoT world, the cost of software updates and fixes in products long obsolete and discontinued will weigh on the balance sheets of corporations for decades, often even beyond manufacturer obsolescence.

Challenge four: A lack of functional value

Many IoT solutions today suffer from a lack of meaningful value creation. The value proposition of many connected devices has been that they are connected – but simply enabling connectivity does not make a device smarter or better. Connectivity and intelligence are a means to a better product and experience, not an end.

It is wishful thinking for manufacturers that some features they value, such as warranty tracking, are worth the extra cost and complexity from a user’s perspective. A smart, connected toaster is of no value unless it produces better toast. The few successes in the market have kept the value proposition compelling and simple. They improve the core functionality and user experience, and do not require subscriptions or apps.

Challenge five: Broken business models

Most IoT business models also hinge on the use of analytics to sell user data or targeted advertising. These expectations are also unrealistic. Both advertising and marketing data are affected by the unique quality of markets in information: the marginal cost of additional capacity (advertising) or incremental supply (user data) is zero. So wherever there is competition, market-clearing prices trend toward zero, with the real revenue opportunity going to aggregators and integrators. A further impediment to extracting value from user data is that while consumers may be open to sharing data, enterprises are not.

Another problem is overly optimistic forecasts about revenue from apps. Products like toasters and door locks worked without apps and service contracts before the digital era. Unlike PCs or smartphones, they are not substantially interactive, which makes such revenue expectations unrealistic.

Finally, many smart device manufacturers have improbable expectations of ecosystem opportunities. While it makes interesting conversation for a smart TV to speak to the toaster, such solutions get cumbersome quickly and nobody has emerged successful in controlling and monetizing the entire IoT ecosystem.

So while technology propels the IoT forward, the lack of compelling and sustainably profitable business models is, at the same time, holding it back. If the business models of the future don't follow the current business of hardware and software platforms, what will they resemble?

3. Democratizing the digital world

The foundation of modern computing is the very humble work of transaction processing. From phone calls to electricity metering, to airline reservations, each is a transaction to be processed. As passengers make reservations, pay for tickets, board planes and receive frequent flyer miles, every step along the way a transaction is processed, recorded and stored.

Transaction processing isn't just for "old-school" workloads, either. Every digital interaction like a message or tweet, is a transaction as well. In today's web-based world, the scale and volume of transactions have exploded. The New York Stock Exchange handles 5 million trades a day. In contrast, over 5 billion social media transactions are processed every single day. Now, along comes the IoT, further exploding the scale and volume of transactions to be processed.

Indeed, transaction processing could not have scaled to its current level without distributed computing. Distributed computing has existed for some time now, as have peer-to-

peer systems. But as recent significant advances in peer-to-peer computing meet Moore's Law, it will soon be possible to harness the compute power, terabytes of storage and bandwidth that will be on billions of devices, in millions of locations and sitting idle most of the time for transaction processing.

Adopting peer-to-peer computing to process the hundreds of billions of IoT transactions can significantly reduce costs associated with installing and maintaining large centralized data centers. It's time for the cloud to move from the data center to your doorknob (see Figure 2).

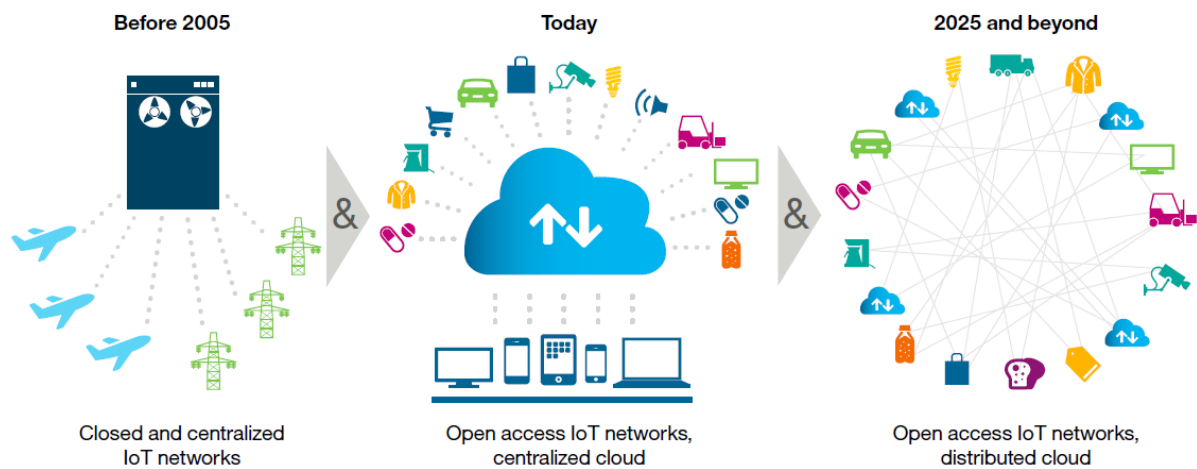


Fig. 2. To be safe, scalable and efficient, Internet of Things networks must be re-architected to gradually shift from managing billions of devices to hundreds of billions of devices

Successful decentralization of the IoT, however, will lie not just in being peer-to-peer, but also in being trustless: an environment in which there is no need for participants to be trusted and no centralized, single point of failure.

In the absence of a centralized server brokering messages, supporting file storage and transfers, and arbitrating roles and permissions, any decentralized IoT solution should support three foundational types of transactions:

- Trustless peer-to-peer messaging
- Secure distributed data sharing
- A robust and scalable form of device coordination.

Peer-to-peer messaging protocols are not new, but emerging trustless peer-to-peer messaging systems promise to provide a "lightweight" mechanism for highly encrypted,

private-by-design communication among devices on the IoT.¹⁴ Our vision is that in the near future, these trustless peer-to-peer protocols evolve into transport protocols more suited for the IoT than TCP/IP. Additionally, secure distributed file-sharing protocols have the potential to replace cloud-based file storage and transfers, enabling secure software and firmware updates, and direct file sharing among peer devices.

The greatest challenge, however, is not in simply building a decentralized IoT, but one that can scale universally while maintaining private, secure and trustless transactions. In other words, the IoT represents a case of billions of players, not all of which can be trusted – some even malicious – with a need for some form of validation and consensus. And for this, the “blockchain” offers a very elegant solution.

4. Why blockchains work for the IoT

A technology breakthrough that has fundamentally changed our notions of centralized authority, the blockchain is a universal digital ledger that functions at the heart of decentralized financial systems such as Bitcoin, and increasingly, many other decentralized systems.

The blockchain holds a record of every transaction made by every participant. Cryptography is used to verify transactions and keep information on the blockchain private. Many participants verify each transaction, providing highly redundant verification and are rewarded for the computational work required. By confirming transactions using decentralized consensus, the blockchain eliminates the need for trust.

While the blockchain may carry regulatory and economic risk as a long-term store of value (as in the case of Bitcoin), it can be quite revolutionary as a transaction processing tool. In our vision of a decentralized IoT, the blockchain is the framework facilitating transaction processing and coordination among interacting devices. Each manages its own roles and behavior, resulting in an “Internet of Decentralized, Autonomous Things” – and thus the democratization of the digital world (see Figure 3).

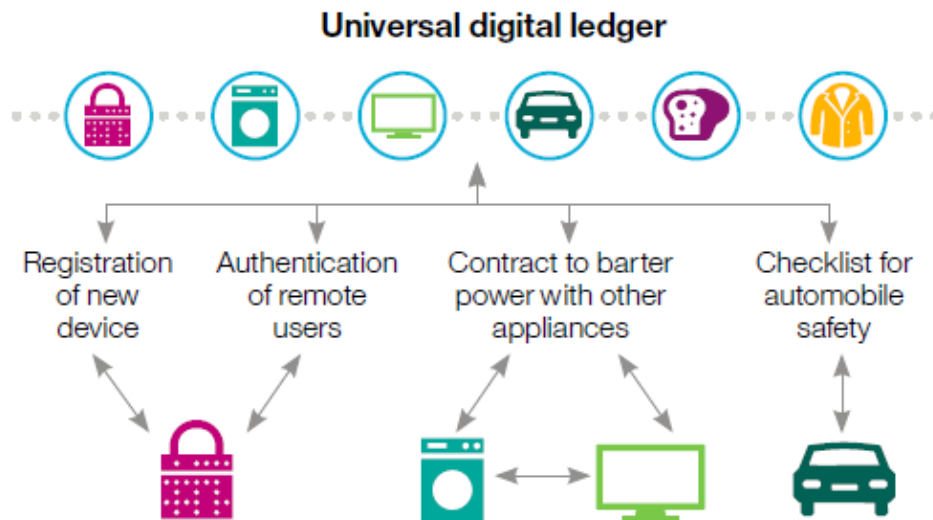


Fig. 3. The blockchain functions as a universal digital ledger facilitating various types of IoT transactions between devices

5. Liquifying the physical world

Before the IoT, there was simply the Internet. The Internet of People (as we may come to know it) has already had an enormous impact on the economy. Its biggest impact, by far, has been in the creation and transformation of markets for digital content such as music, news, maps and other information.

The IoT will enable a similar set of transformations, making the physical world as liquid, personalized and efficient as the digital one. Based on historical case studies of digital disruption, we see five compelling vectors of disruption emerging. They will shift the IoT from technical curiosity to compelling business strategy (see Figure 4).

Vectors of disruption	Liquification of the physical world
Unlock excess capacity of physical assets	Instantly search, use and pay for available physical assets
Create liquid, transparent marketplaces	Real-time matching of supply and demand for physical goods and services
Enable radical re-pricing of credit and risk	Digitally manage risk and assess credit, virtually repossess and reduce moral hazard
Improve operational efficiency	Allow unsupervised usage of systems and devices, reduce transaction and marketing costs
Digitally integrate value chains	Enable business partners to optimize in real-time, crowdsource and collaborate

Fig. 4. Five vectors of disruption: How the IoT will increase our leverage of physical assets

Unlocking excess capacity of physical assets

In transforming the market for digital content, the Internet enabled three key elements of commerce: search, usage and payment. Search became instant and comprehensive. From

music to encyclopedia articles, usage and payment can similarly take place immediately and entirely online. Some of the transformation that has taken place is a result of the unique economics of digital content. With a zero marginal cost of reproduction, market clearing prices for competitive digital markets have reached zero.

The IoT creates the ability to digitize, sell and deliver physical assets as easily as with virtual goods today. Using everything from Bluetooth beacons to Wi-Fi-connected door locks, physical assets stuck in an analog era will become digital services. In a device driven democracy, conference rooms, hotel rooms, cars and warehouse bays can themselves report capacity, utilization and availability in real-time. By taking raw capacity and making it easy to be utilized commercially, the IoT can remove barriers to fractionalization of industries that would otherwise be impossible. Assets that were simply too complex to monitor and manage will present business opportunities in the new digital economy.

Creating liquid, transparent marketplaces

By identifying and matching supply and demand for physical assets and services in real-time, the IoT will create new marketplaces. These complex, real-time digital marketplaces will build upon the foundation established by mobile devices and social networks to expand the reach of this transformation very quickly. They will enable new peer-to-peer economic models and foster sharing economies.¹⁶ Devices will be able to compete in real-time, be reviewed and recommended by consensus, and trade on their own, resulting in highly efficient digital marketplaces.

There is no better historical example of what happens when a continuous flow of capacity and services meets a powerful set of digital tools to match supply and demand than the role of Sabre in the airline industry. Uber and Airbnb are the Sabres of today, leading the creation of liquid markets for physical assets such as cars, homes, office cubicles, urban storage, parking spots and appliances that would not be possible without the IoT.

Radical re-pricing of credit and risk

Another big revolution will be in the creation of personalized risk and credit profiles. The provision of credit and management of risk today is a crude business, as crude as advertising was in the era of newspapers and television. Credit bureaus and tax records in mature western markets sparked a revolution in the availability of consumer credit, but they cover (crudely)

only a tiny portion of the world's population. Unsecured credit lines in mature markets like the U.S. are often 8 to 10 times the cost of high quality credit, with remarkably little variation among customers, a testament to how poorly risk pricing is understood even in those markets.

Instrumentation and digitization enabled by mobile phones and the IoT promise a revolution in pricing risk and credit. Combining device instrumentation with mobile money, GPS logs and social networks, it will be possible for companies to build much more accurate pictures of real risk, and simultaneously reduce moral hazard and the cost of repossession.

The expansion of consumer credit at reasonable prices had an enormous impact on the prosperity of consumers, and the spread of modern appliances and other conveniences into homes. Together, the unlocking of physical assets, creation of new markets and more accurate assessment of credit and risk will open the doors to new digital economies inconceivable before the IoT

Improving operational efficiency and digitally integrating value chains

Finally, there are whole sectors of the economy where information technology is yet to make any significant impact. In these sectors, not only is there the possibility to unlock assets, create new markets and better price risk, but the opportunity is highest to improve efficiency and create entirely new solutions and value (see Figure 8). By definition, it is hard to forecast entirely new kinds of value, but a good place to start will be those industries that, to date, have felt little impact from digitization.

6. Conclusion:

As the IoT liquifies the physical world, it will transform many products and experiences by embedding connectivity and intelligence in practically everything around us. To most users of these devices though, networking and remote usage are only secondary features. Consumers care most about the primary functional value and user experience.

At a macroeconomic level, we are all winners in the IoT future, even though different industries will experience a mix of different effects. Overall growth is likely, but profit pools will not be preserved, nor will the distribution of benefits be even. Success will be for those that:

- enable decentralized peer-to-peer systems that allow for very low cost, privacy and long term sustainability in exchange for less direct control of data
- prepare for highly efficient, real-time digital marketplaces built on physical assets and services with new measures of credit and risk
- design for meaningful user experiences, rather than try to build large ecosystems or complex network solutions.