The Case for Open Ecosystems for the Internet of Things

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Abstract. The importance of market-based innovation and user innovation is widely accepted, but the development of the emerging Internet of Things is entirely driven by market forces. Using an ecosystem perspective, this paper identifies how market-based and user innovation can be combined in a mutually dependent way. Case studies of an industrial project and the smart-home domains are used to identify challenges for the realization of open Internet of Things ecosystems.

Keywords: Internet of Things, software ecosystem, user innovation, software business

Introduction

The iPhone and the iPhone application store have unleashed an unprecedented wave of innovation. Not only have they given consumers seamless access to a vast number of mobile phone applications, it has also enabled individuals with a minimum of programming skills, including 10 year old children, to reach a mass audience for their applications. iPhone applications range from the mundane to applications for charities, social activism, environmental product information and citizen journalism. Undoubtedly the iPhone platform has empowered people and created a new medium for informed citizenship. As researchers (including ourselves) are working towards the realization of the Internet of Things (IoT), we are faced with the question of how to ensure that the emerging Internet of Things empowers people, citizens and non-commercial entities in the same way the iPhone has in the mobile space.

The Internet of Things is seen as the next great revolution in IT. While related paradigms such as mobile computing, ubiquitous computing and pervasive computing have pushed the notion of *anytime*, *any place* connectivity for *anyone,* the term Internet of Things is used to conjure visions of a world of connected objects and items, i.e. connectivity for *anything* [1]. Currently, the Internet of Things is closely associated with RFID technology and industrial applications. The success of these applications - and the commercial drivers behind them - has created a huge momentum that pushes technical developments and public discourse in one direction. Unless we willfully expand the discussion and assign the needs, desires and fears of

ordinary citizens as much importance as the requirements of industrial players there is the danger that the Internet of Things falls short of its potentials.

This is not unchartered territory. Surveying the recent literature we can broadly identify two approaches of how to address people's concerns: On the one hand, researchers have developed concrete application scenarios and prototypes that demonstrate how the Internet of Things can benefit people [2]. On the other hand, researchers have stressed the active role of the end-user in shaping the IoT. For example Micheahelles argued in [3] that giving end-users the tools to create and invent IoT applications is a way to ensure that people's concerns will be adequately addressed, and Kawsar demonstrated how empowering end-users in building IoT in a Do-it-Yourself fashion substantially elevates users' experiences [4].

However, there is a third - complementary - way of addressing people's concerns, namely by focusing on market-based mechanisms and ecosystems [14,15,16] as enablers of innovation. As the iPhone example shows, market-based innovation approaches and user-led innovation approaches go hand in hand. Only by having access to the iPhone distribution channel and associated tools do user generated innovations find the massive audience that is required to make an impact.

The question then is: How can we recreate or encourage similar mechanisms for the Internet of Things? How can we foster ecosystems around the IoT that enables commercial software/hardware vendors to market, sell and distribute innovative IoT applications and services to consumers? How can the same ecosystem enable people with minimal technical skills to disseminate and possibly monetize their innovative IoT products?

The contribution of this paper is threefold. First, it identifies the importance of combining user-led and market-based innovation mechanisms to ensure that the IoT benefits citizens and non-industrial entities. Second, it defines the notion of an open ecosystem, applies it to the Internet of Things and argues how such ecosystems foster user innovation. Third, it discusses challenges for the realization of open IoT ecosystems.

An Internet of Things Case Study

Ecosystems (in particular software ecosystems) have been identified as one of the major forces for innovation [14, 15]. The term is used to describe the technical, social and business context in which software is created, distributed, deployed and used. More specifically, we define ecosystems as the set of business and social entities (developers, vendors, users) and the technical components and solutions (hardware and software) that enable and support the activities and transactions by the ecosystems actors [16]. Having introduced ecosystems in the discussion we will continue with an example of how current IoT research ignores ecosystem concerns. The example is taken from our own work on industrial health and safety monitoring systems [5,6]. The point here is not to rehash the underlying research, but to review the processes and results from an innovation perspective.

As part of a large collaborate research project we have worked with a user organization (a large construction firm) and an independent system integrator to

develop smart sensor solutions for road construction work sites [5]. Initially driven by the concerns of management the project explicitly investigated and addressed concerns of workers. The result of our engineering effort is a custom-tailored system that is closely aligned with the needs and requirements of the user organization. The development process was a step-wise refinement from requirements to implementation (Figure 1). While the bespoke development process is appropriate and typical for an industrial context, it has a number of disadvantages:

- The design focuses on the needs of single organization and within the organization on the requirements of management. Despite intensive focus on workers' concerns (involving for example extensive ethnographic studies) the realities were such that actual engineering focus was on short-term business-relevant interests related to asset tracking. This was despite the fact that our research uncovered interesting opportunities for user-led innovation in health and safety monitoring. For example, we found evidence for emerging practices in the use of the personal safety devices and the opportunities for bottom-up user-driven design approach [6].
- The resulting system can best be described as a closed solution. In particular there are no provisions for independent third-party developers to create applications, add-ons or extensions. The only actors in the development process are business analyst and system analyst (in-house) and system integrator and hardware provider.
- Finally, we have to note the slow pace of innovation related to the closed systems approach. Ideas for novel application scenarios and extension of the system must make their way through the lengthy top-down development process that prevails in industrial organizations.

We believe that our experience is not atypical for projects in the IoT space. Perhaps the closed systems approach was inevitable given the development practices and business concerns of an industrial organization. Yet while in the wider IoT space there are efforts to create open or semi-open standards like EPC [17], the resulting systems and solutions are similarly closed.

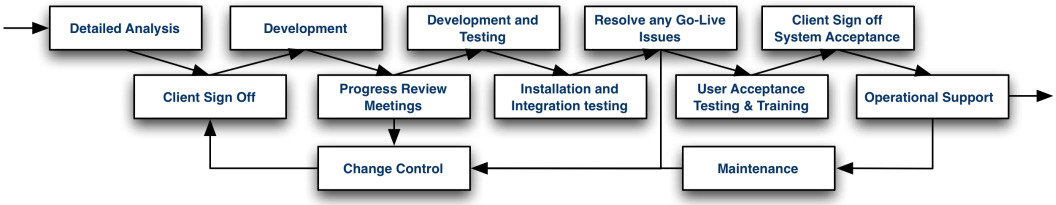

Figure 1. Development Process for an Industrial Internet of Things Systems

How an Open Internet of Things Ecosystem Might Look Like

For the following discussion we leave the construction domain and use smart-homes as example. Smart-homes have been a focus of intensive research ubiquitous and pervasive computing, and as we will see are also an important realm for the Internet of Things. Traditionally smart-home research has focused on enabling

technologies (sensing and algorithms) [11,12], applications (elderly care) and user issues [7]. As in other areas, the importance of user-led innovation has been recognized early on and there is important work on tailorability and end-user programming of smart-homes [9,10,13].

However, there is a curious lack of research on how smart-homes may come into existence and evolve over time. Most work in this area views smart-homes as a single complex system that is designed and developed (constructed) from the ground up and that most aspects (physical building, digital infrastructure, furniture, appliances) are under the control of the smart-home developer. This might be the right assumption if one considers research facilities such as Georgia Tech's smart-home [20], but it is certainly wrong if one considers the typical life cycle and evolution of homes [8]. The key observation about buildings is that in practice they are assemblies put together by many contributors: an electrician adds wires and lighting, a plumber adds water and heating system, the inhabitants add furniture, electrical appliances etc. Thus rather than viewing a smart-home as a single complex system designed and developed by a single entity, we want to advance the notion of a *smart-home ecosystem*. A *smart-home ecosystem* is a set of actors (business and individuals) who interact and collaborate in the construction, upkeep and use of smart-homes, together with software/hardware components that make up a smart-home.

Figure 2 shows the actors of an envisioned smart-home ecosystem.

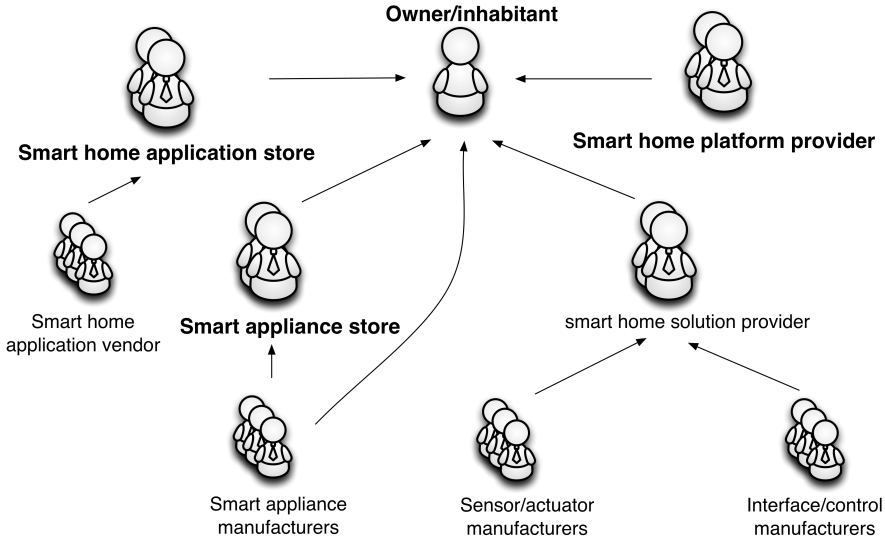

Figure 2. IoT Ecosystem for Smart-homes (actors)

The smart-home ecosystem consists of the following products and components (Figure 3):

– **Smart-home software platform**: this platform provides software abstractions to all subsystems and services of a smart-home, much in the same way an operating systems does for a computer.

- **Sensor and actuators**: these represent the basic infrastructure for activity recognition and automation.
- **Smart appliances**: these include (future versions of today's) appliances like stove, dishwasher, lights, etc.
- **Interfaces and controls**: This category includes everything that allows inhabitants to control a smart-home and includes simple switches, digital displays etc.
- **Smart-home applications**: applications are the loci of end-user functionality, much in the same way a word processor provides end-user functionality on top of a computer operation system.

The key actors in the ecosystem are the **owner/inhabitant**, **platform providers**, **application providers**, **application store** (i.e. the business that runs it), and **smart appliance store**. Platform providers compete with each other for the best smart-home solution, independent developers create and market smart-home applications built on top of these platforms, distributors collect and bundle applications, and inhabitants seek out and purchase entertainment, security, comfort and life-style applications for their home and the objects it contains.

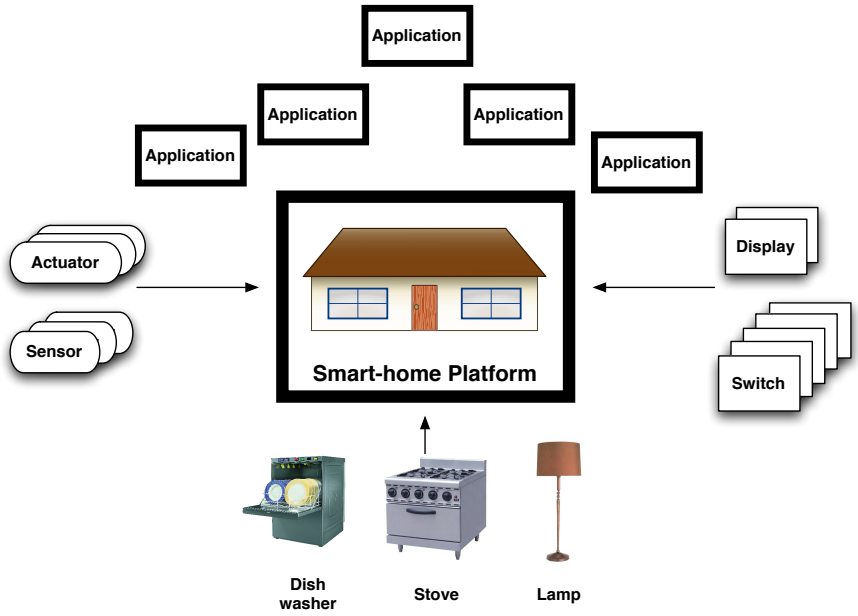

Figure 3. IoT Ecosystem for Smart-homes (technology)

There are two key points we want to emphasize: 1) this is just one possible example of how a smart-home ecosystem might be emerge; depending on the technology, business models and business strategies we would see an almost infinite number of ecosystem variations. 2) Many of the components are physical objects and appliances that the home owner/inhabitant purchases and places in her home (turning this ecosystem into a true IoT ecosystem). These objects must become an integral part

of the smart-home without requiring manual configuration, a task that must be ensured by the combined technology of the ecosystem.

Ecosystems are enablers of innovation. They channel demand from the end-user to distributors and providers, encouraging them to develop innovative products in response. Similarly, ecosystems make it possible for user innovations to emerge, to be disseminated and to find a receptive audience of like-minded people. We argue that a properly "configured" smart-home ecosystem can do for innovation in smart-homes what the iPhone ecosystem has done for innovation in the mobile space. A smart-home ecosystem as outlined above might for example enable a home-owner to develop an energy measurement application for her home and make it available to other home owners/renters through the application store. Crucial here is that this kind of user innovation depends on a rich set of technical smart-home capabilities, which are provided by the ecosystem and its commercial and non-commercial actors. Without the existence of such an ecosystem user innovation would not be effective, i.e. not be able to reach scale.

What Needs to be Done to Enable Open IoT Ecosystems?

Ecosystem approachs are increasingly gaining attention in software business research [15], but so far have not been applied to the Internet of Things. While local IoT ecosystems certainly exist in the industrial realm, for example associated with specific RFID system and platforms, they are poorly understood. More importantly, existing IoT ecosystems are not open to individuals in the same way the iPhone ecosystem is and thus do not support user-led innovation. Empowering citizens to make full potential of the IoT requires ecosystems that are shaped to allow lead users access to development, production and distribution capabilities. In the following we highlight four key challenges for the emergence/purposeful creation of open IoT ecosystems.

Challenge 1: Identifying and mapping potential open IoT ecosystems

Smart-homes are just one example of where an ecosystem approach could be beneficial. The challenge is to identify other domains, in which ecosystems may emerge, to map them out in terms of technical components and business actors, and to understand how they will support market-based and user-led innovation. As [16] showed for software, ecosystems can be defined on different system levels (platforms, applications, languages, …) thus there is an almost unlimited variety of possible ecosystems. The difficulty is that in general the working of ecosystems is not well understood [15] and has not yet been applied in an attempt to create an environment that encourages user innovation in the context of the Internet of Things.

Challenge 2: Understanding the characteristics of open innovation platforms for the IoT

Platforms are at the heart of many hardware/software ecosystems (Personal Computer, Windows operating systems, Salesforce.com) [18,19] and will likely play an important role for the IoT. The challenge is to understand what makes a compelling IoT platform from a business and engineering point of view. What abstractions should these platforms expose to maximize adoption and innovation?

IoT platforms are more complex than software platforms such as Microsoft Windows in that they must dynamically integrate sensors and actuators as well as smart objects. How do these platforms manage interoperability between components and products from different vendors?

Challenge 3: Understanding and supporting user innovation touchpoints and collaboration

User innovation in the smart-home example can occur in many ways: by developing innovative smart-home applications, by creating or modifying smart objects and appliances, by upgrading the sensor / actuator infrastructure etc. The challenge is to identify these innovation touchpoints and to provide adequate tools. Application development can be supported in the traditional by providing software toolkits. How do toolkits look like for modifying smart appliances? How can these modifications be disseminated to other owner/users in effective ways? How can collaboration and sharing of user-generated artefacts be supported by the ecosystem?

Challenge 4: Identifying business & pricing models

IoT ecosystems create opportunities for novel business relationships and business models. Would a future smart appliance that provides information about its use back to the manufacturer be sold like appliances today, would it be rented on per-usage basis or would it be provided for free in return for access to user data? The challenge is to identify new business models related to smart physical objects and to develop technical means for supporting them within the ecosystem (for example by facilitating capture and transmission of user data between smart-home and appliance manufacturer). As of now we do not know how to price the value of IoT services and applications in an open market place. We do not have business models that would allow IoT vendors to compete by functionality, service level or quality.

Addressing these four challenges requires interdisciplinary, collaborative research in computer science, software engineering, software business management, and economics. Most of the raised questions are not new, but they will gain renewed importance and require new answers in a world of physical/digital products and sensor-rich environments.

Conclusion

Concerns about the direction of the development of the Internet of Things are rising. In order to supplement the influence of industrial IoT players we need to look for ways to foster user innovation in a similar way to what the iPhone ecosystem has achieved for mobile computing. Research into ecosystems is at the beginning and thus far has not been applied to the Internet of Things. We argue that technical decisions about platforms, as well as business decisions about business models and strategy must go hand-in-hand. Most importantly, we see market-based innovation and user-let innovation as necessary complements for the way forward in developing the Internet of Things.

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