User Innovation for the Internet of Things

Gerd Kortuem and Fahim Kawsar

Computing Department, Lancaster University, UK
{kortuem, kawsar}@comp.lancs.ac.uk

Abstract. The importance of user innovation is widely accepted, but the development of the Internet of Things is primarily driven by large commercial players. Using an innovation perspective, this paper identifies how user innovation and market-based innovation can be combined by creating user-centered ecosystems that are open for and provide incentives for end-user innovation. An investigation of the smart-home domain is used to identify challenges for the realization of user-centered ecosystems for the Internet of Things.

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

1 Innovation By Users, For Users

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, they have also enabled individuals with a minimum of programming skills to reach a mass audience for their applications. As result the iPhone platform has empowered people and created a new medium for informed citizenship, social activism and citizen journalism. 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 supports user-led innovation and empowers ordinary people, citizens and non-commercial entities in the same way the iPhone has done in the mobile space.

The Internet of Things is seen as the next 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 [2]. According to the Open Source Sensing Foundation "a long and expensive battle is looming" over privacy, accuracy, ownership and sovereignty "between those using sensors to collect data and those whose data is being collected" [3].

The question of how to address citizen's concerns in the development of the Internet of Things is not unchartered territory. Surveying the recent literature we can broadly identify two approaches: on the one hand, researchers have developed concrete Internet of Things products that benefit ordinary people [4]. On the other hand, researchers have stressed the active role of the end-user in shaping the IoT. For example Michahelles argued in [5] 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 can elevate users' experiences [6]. These approaches are in line with von Hippel and Katz's observation that by providing users with adequate toolkits it is possible to shift innovation from companies to end users [7].

However, providing user with development tools is not enough, as innovation requires successful *diffusion* (the process by which an innovation is communicated among potential users) as well as *adoption* (the decision making processes of the eventual user/buyer/consumer). Thus, if we want to ensure that end-users are capable of producing and disseminating innovations we need to ensure that they can effectively communicate and distribute their ideas and products. The iPhone[1] example shows how this can be achieved by paying particular attention to market-based mechanism. By combining programming tools, application platform and distribution channel, Apple has created an environment that effectively supports *user innovation networks* [8] in which innovation development, production, distribution and consumption are performed by users (or more precisely by user/developers and micro software firms). von Hippel proposes that "user innovation networks can function entirely independently of manufacturers when (1) at least some users have sufficient incentive to innovate, (2) at least some users have an incentive to voluntarily reveal their innovations, and (3) diffusion of innovations by users is low cost and can compete with commercial production and distribution." [8, p.3]. The user innovation network supported by the iPhone ecosystem is *horizontal*, where innovation – in the form of iPhone apps – is created by and for users[2]. In contrast to von Hippel's notion, which refers to open-source development and the ability to replicate and adapt a product, the iPhone innovation network does not compel users to make their innovations openly accessible to other users. Instead, the transfer of innovation among users is facilitated by a two-sided market (realized by the App Store), with user/developers on the one side and users-only on the other[3]. The network effects realized by this market enable the effective transfer of ideas (in the form of applications) and the effective recruitment of users for application that require large

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[1] For simplicity we focus on Apple and the iPhone, even though increasingly other mobile vendors such as Nokia, Google, Microsoft, Palm and RIM replicate elements of the iPhone ecosystem.

[2] User-led innovation complements traditional commercial innovation.

[3] The term 'market' does not imply commercial transactions – indeed the majority of iPhone software downloads involve free software (the ratio of paid/free apps is 1.8 to 7 [9]).

user populations to become successful (for example, crowd sourcing and participatory sensing applications). In sum, even though the iPhone ecosystem has been a boon to commercial software developers and primarily has been created to benefit Apple, it has "democratized innovation" [10] and *paved the way for user-led innovation*[4]. In turn this has led to the successful development and adoption of applications for social activism [11], citizen science [12,13,14], and citizen journalism [15].

Regarding the Internet of Things, the question then is: How can we give ordinary citizens a voice, not just as commentators of ongoing IoT developments, but as innovators and shapers of technology? How can we ensure that the Internet of Things allows for user-led innovation (in addition to company-driven innovation)? How can we create or encourage innovation mechanisms for the Internet of Things similar to the market-based mechanisms employed by Apple (and increasingly other mobile vendors)?

In the remainder of this paper, we provide preliminary answers to these questions. Our aim is to highlight the importance of combining user-led and market-based innovation mechanism for the future development of the Internet of Things. We introduce *user-centered ecosystems* as a theoretical framework and, using the smart home domain as example, argue how such ecosystems foster user innovation. Finally we identify five challenges for the realization of user-centered IoT ecosystems.

2 Open and User Innovation for the Internet of Things

The Internet of Things differs from the Internet and the Web in that its initial development has been driven by large industrial players and commercial interests. While this continues to be the case, we can witness efforts to open up the Internet of Things and to make its development more inclusive. Many of the most interesting ideas in the IoT space currently emerge from "innovation communities" of artists, designers, hobbyists, researchers, and small technology firms dedicated to creating and freely disseminating innovations (examples include ThingM [16], Tinker [17] and Berg London [18]). An important aspect of this global community is the development of *open source software and open hardware* platforms for unrestricted prototyping and experimentation (for example, Arduino [19]). The cooperative, community-minded spirit of open source projects is also extending to data aspects of the IoT [3].

The development of *open standards* for the IoT is another key trend. Under the label 'Web of Things' [20], universities and commercial players alike are working towards the development of open protocols that connect objects to the Web, for example by exploring RESTful web service infrastructures for objects [21,22]. Compared to proprietary standards, open standards create a more level playing field for innovation and thus make it possible for smaller players to be effective innovators (even though most open standards like IPSO [23] are pushed by large industry players). Smaller, independent players increase the chances that innovations will emerge that benefit citizens, not just narrow commercial interests.

Despite these welcome developments in open innovation, the potential role of end-users as instigators and creators of IoT innovations has not yet been explored in any

[4] This despite the fact that Apple tightly controls iPhone platform, tools and app store.

depths as existing work focuses on tool support alone [6, 24]. As the iPhone example shows, grassroots innovation can emerge within a (strictly controlled) market place if there is space in the ecosystem for end-users to find an audience and to gain from sharing their innovations. As open-source movement and the large number of free iPhone apps testifies, gain does not necessarily mean financial gain, but in most cases relates to personal satisfaction and public recognition. Market-based innovation communities are not limited to software and digital products, but also have been established for self-made physical goods. For example, Ponoko [25] is a successful online marketplace for self-made physical things (a "digital making community"), which allows designers, creators, digital fabricators, materials suppliers and buyers to collaborate in the making of things.

In the next section we investigate how an *open marketplace* for IoT might be realized that enables people with minimal technical skills to create, distribute, and possibly monetize their innovative IoT products within a community of user/developers. For that purpose, we focus our attention on smart homes, an important realm for the Internet of Things, especially with respect to the recent upswing in smart energy solutions.

3 Towards User-Centered Ecosystems

Traditionally smart-home research has focused on enabling technologies and applications [26]. Increasingly, research projects aim at establishing technical and business ecosystems [27,28], but these efforts are primarily vendor-driven and supply-side focused without looking at end-user innovation[5]. Academic researchers, on the other hand have investigated end-user programming and tailorability of smart-homes [30,31], but this work ignores the important diffusion aspect of innovation.

In order to address this shortcoming we advance the notion of a *user-centered smart-home ecosystem* as a set of actors (business and individuals) that interact and collaborate in the construction, upkeep and use of smart-homes, together with enabling software/hardware components. The key purpose of the user-centered ecosystem (and the main difference to non-user-centered ecosystems) is to enable owner/inhabitants to *create, deploy and disseminate smart home innovation* in the form of new hardware and software applications.

In order to enable this key purpose an number of ecosystem players must be exist: platform providers, application providers, application store, and a smart appliance store, among others (Figure 1). 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, and distributors collect and bundle applications. Owners/inhabitants use the application and appliance store to disseminate their self-developed entertainment, security, comfort and life-style applications and seek out and purchase applications produced by commercial players and other owner/inhabitants.

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[5] The only notable exception is the Do-it-Yourself Smart Experiences project (DiYSE) (www.dyse.org), but concrete results are still sparse [29].

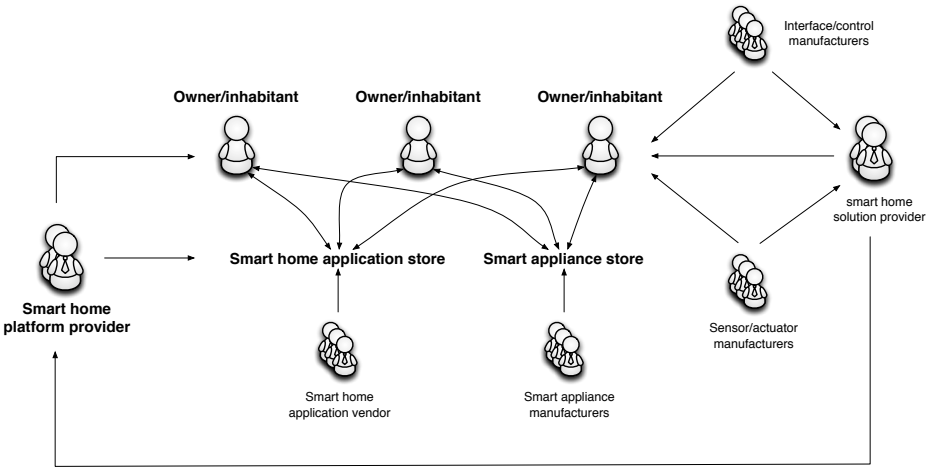

Figure 1. IoT Ecosystem for Smart-homes (actors)

Most research views smart homes as a single complex system that is designed and constructed from the ground up, and assumes that most aspects (physical building, digital infrastructure, furniture, appliances) are under the control of a single smart-home developer. This might be the right if one considers research facilities such as Georgia Tech's smart-home [32], but is certainly wrong if one takes into account the typical life cycle and evolution of homes [33]. The user-centered ecosystem above reflects the fact that buildings are assemblies put together by many contributors and that do-it-yourself home improvements by owners/inhabitants play an important role over the lifetime of a home.

The smart-home ecosystem must be supported by a corresponding technical infrastructure that supports the ability of owners/inhabitants to adjust and improve their home's working, and supports the implied business relations between commercial players. An example of such a smart home infrastructure is shown in Figure 2 and consists of the following components:

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 and units of end-user development.

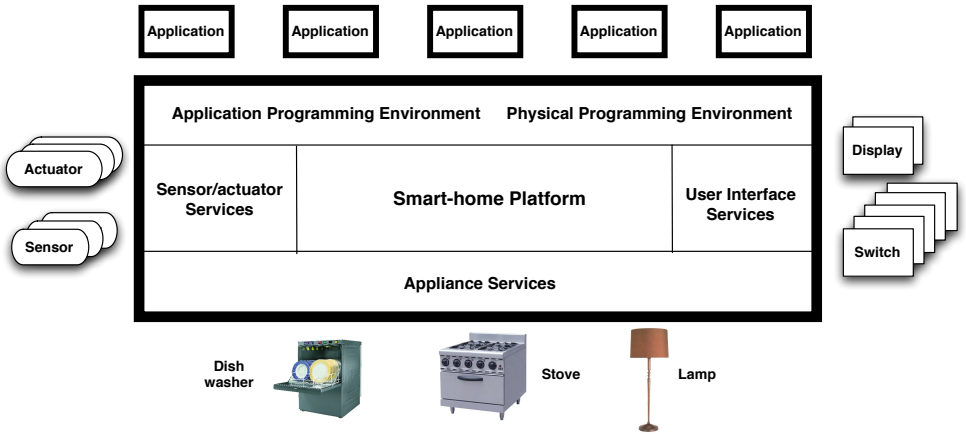

Figure 2. IoT Ecosystem for Smart-homes (technology)

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" user-centered 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 homeowner 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. would not be able to reach scale.

Smart home and IoT ecosystems are more complex than the iPhone ecosystem for a number of reasons: (1) IoT products may be physical as well as digital, and not just software applications. (2) Much of the value of the IoT depends on data captured by embedded sensors, for example data about energy consumption. Data may itself become a tradable commodity in an IoT market, so that users may be able to sell their data to other ecosystem actors. (3) An IoT market will involve many more partners than the relatively straightforward two-sided market for iPhone applications. Just as a home is constructed and maintained by electricians, painters and plumbers we can expect an IoT ecosystem to involve many specialized players and - perhaps - multiple specialized markets.

4 Challenges for User-Centered Ecosystems

Ecosystem approaches are increasingly gaining attention in software business research [34,35], 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 not open to individuals in the same way the iPhone ecosystem is and thus do not support user-led innovation. Empowering end-users to create their own smart Internet-of-Things experiences requires ecosystems that remove barriers for creation and distribution. In the following we highlight five key challenges for the emergence/purposeful creation of user-centered IoT ecosystems.

Challenge 1: Understanding and supporting user innovation touchpoints

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 sharing of user-generated physical artefacts be supported by the ecosystem?

Challenge 2: Understanding the characteristics of open innovation platforms

Platforms are at the heart of many hardware/software ecosystems [36] 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 complex 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 user incentives

Incentives are at the core of user innovation. On the one extreme, user/developers may simply value the process of innovating because of the enjoyment or learning that it brings them; on the other extreme, they may be able to monetize their innovation by selling products on an open market place. The sensor richness of the Internet of Things adds novel trading and monetization opportunities related to user-generated data. What are suitable monetization strategies for user-generated data? How can users resolve the conflict between maintaining privacy and realizing potential value of data? How can users trade or collect user-generated data without involving monetary transactions?

Challenge 4: Identifying IoT business 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-generated 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.

Challenge 5: Identifying and mapping potential open IoT ecosystems

Smart-homes are just one IoT 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. Software ecosystems can be defined on different system levels (platforms, applications, languages, …) [34,35], thus there is an almost unlimited variety of possible ecosystems. Relevant research has not yet been applied in an attempt to create an environment that encourages user innovation in the context of the Internet of Things.

Addressing these five 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.

5 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. As IoT end users are empowered to create and share their own innovations they will become producers in a newly emerging ecosystem in which users/developers and companies can fruitfully cooperative. We argue that decisions about platforms and business models must go hand-in-hand. Most importantly, we see market-based innovation and user-led innovation as necessary complements for the way forward in developing the Internet of Things.

References

[1] International Telecommunication Union (2005). The Internet of Things. Internet Report 2005. Available at http://www.itu.int/osg/spu/publications/internetofthings.

[2] van Kranenburg, R (2007). The Internet of Things: A critique of ambient technology and the all-seeing network of RFID, Network Notebooks 02, Institute of Network Cultures, Amsterdam, 2007.

[3] Open Source Sensing Initiative (2010). Home page http://opensourcesensing.org. [Accessed 2 April 2010].

[4] Guinard, D., Baecker, O., & Michahelles, F. (2008). Supporting a Mobile Lost and Found Community. In Proceedings of the 10th International Conference on Human-Computer Interaction with Mobile Devices and Services (pp. 407-410). New York.

[5] Michahelles, F (2009). How the Internet of Things will gain momentum: Empower the users, Invited Paper, International Conference of Impact on Ubiquitous RFID/USN Systems to Industry, Sunchon, Oct 6, 2009.

[6] Kawsar F. (2009). A Document-Based Framework for User Centric Smart Object Systems, PhD dissertation, Dept. Computer Science, Waseda Univ., Feb. 2009.

[7] von Hippel, E., & Katz, R. (2002). Shifting Innovation to Users via Toolkits. Management Science, 48(7), 821-833.
[8] von Hippel, E. (2002). Open Source Projects as Horizontal Innovation Networks - By and For Users (June 2002). MIT Sloan Working Paper No. 4366-02. Available at SSRN: http://ssrn.com/abstract=328900
[9] Admob.com (2010). January 2010 Mobile Metrics Report, (Available online at http://metrics.admob.com/2010/02/january-2010-mobile-metrics-report/)
[10] von Hippel, E. (2005). Democratizing Innovation. MIT Press.
[11] The Extraordinaries. http://app.beextra.org
[12] The WildLab. http://www.thewildlab.com
[13] Noah· http://www.networkedorganisms.com
[14] SparkVue. http://www.pasco.com/featured-products/sparkvue-for-iphone/index.cfm
[15] 360News. http://www.360ne.ws
[16] ThingM http://thingm.com
[17] Tinker http://www.tinker.it
[18] Berg London http://berglondon.com
[19] Arduino· http://www.arduino.cc
[20] Trifa, V. and Guinard, D (2010). Towards the Web of Things, Whitepaper 1.0. Available online at http://www.scribd.com/doc/16292620/Web-of-Things-whitepaper-v1
[21] Stirbu, V. (2008). Towards a RESTful Plug and Play Experience in the Web of Things. In Semantic Computing, 2008 IEEE International Conference on, 512-517, 2008.
[22] Wilde, E. (2007). Putting Things to REST, UCB iSchool Report 2007-015, School of Information, UC Berkeley, 2007.
[23] IPSO http://www.ipso-alliance.org
[24] Guinard, D. and Trifa, V. (2009) Thomas Pham and Olivier Liechti. Towards Physical Mashups in the Web of Things. In International Conference on Networked Sensing Systems, INSS 2009.
[25] http://www.ponoko.com
[26] Chan, M., Estève, D., Escriba, C., and Campo, E. (2008). A review of smart homes-Present state and future challenges. Comput. Methods Prog. Biomed. 91, 1 (Jul. 2008), pp. 55-81.
[27] http://www.sofia-project.eu
[28] http://www.diem.fi
[29] Trappeniers, L., Roelands, M., Godon, M., Criel, J., Dobbelaere, P. (2009). Towards Abundant DiY Service Creativity. Successfully Leveraging the Internet-of-Things in the City and at Home, ICIN 2009, Bordeaux, September 2009
[30] Davidoff, S., Kyung Lee, M., Yiu, C., Zimmerman, J. and Dey. A (2006). Principles of Smart Home Control. In Proceedings Ubicomp 2006.
[31] Kawsar, F., Nakajima, T., Fujinami, K. (2008). Deploy spontaneously: supporting end-users in building and enhancing a smart-home. In Proceedings UbiComp 2008, pp. 282-291.
[32] http://awarehome.imtc.gatech.edu/
[33] Rodden, T., Benford, S. (2003). The evolution of buildings and implications for the design of ubiquitous domestic environments. Proceedings of the conference on Human factors in computing systems '03, 9 – 16, 2003.
[34] Jansen, S., Brinkkemper, S., Finkelstein, A. (2009). A Sense of Community: A Research Agenda for Software Ecosystems. 31st International Conference on Software Engineering, New and Emerging Research Track, 2009.

[35] Bosch, J. (2009). From Software Product Lines to Software Ecosystems. 13th International Software Product Line Conference, August 2009.
[36] Evans, D., Hagiu, A., Schmalensee. R. (2006). Invisible Engines. How software platforms drive innovation and transform industries. MIT Press 2006.