Bootstrapping Smart Cities through a Self-Sustainable Model Based on Big Data Flows

Ignasi Vilajosana, Jordi Llosa, Borja Martinez, Marc Domingo-Prieto, and Albert Angles, Worldsensing
Xavier Vilajosana, Worldsensing, University of California Berkeley, and Universitat Oberta de Catalunya

ABSTRACT

We have a clear idea today about the necessity and usefulness of making cities smarter, the potential market size, and trials and tests. However, it seems that business around Smart Cities is having difficulties taking off and is thus running short of projected potentials. This article looks into why this is the case and proposes a procedure to make smart cities happen based on big data exploitation through the API stores concept. To this end, we first review involved stakeholders and the ecosystem at large. We then propose a viable approach to scale business within that ecosystem. We also describe the available ICT technologies and finally exemplify all findings by means of a sustainable smart city application. Over the course of the article, we draw two major observations, which are seen to facilitate sustainable smart city development. First, independent smart city departments (or the equivalent) need to emerge, much like today's well accepted IT departments, which clearly decouple the political element of the improved city servicing from the underlying technologies. Second, a coherent three-phase smart city rollout is vital, where in phase 1 utility and revenues are generated; in phase 2 only-utility service is also supported; and in phase 3, in addition, a fun/leisure dimension is permitted.

INTRODUCTION

Urban living is beginning to take a central role in the direction in which humanity is evolving. Today, more than half the population is living in urban environments [1]; the related efforts to facilitate viable living conditions are tremendous [2]; and, to make matters worse, the effect of urbanization on the global climate has come into the limelight [3]. Solutions are urgently needed, and quickly advancing technologies may just be the answer. Urged by the above observations, city halls and political decision makers have become very sensitive and alert. This has triggered Cisco, IBM, HP, and other global information and communications technology (ICT) players to launch their own smart planet and smart city initiatives. For good reason: the smart city market is estimated to be hundreds of billions of dollars by 2020, with annual spending reaching nearly $16 billion [4].

Pike Research [4] defines a smart city as "the integration of technology into a strategic approach to sustainability, citizen well-being, and economic development." Viable smart city models thus ought to be "multi-dimensional, encompassing different aspects of smartness and stressing the importance of integration and interaction across multiple domains." A city, in the end, is a system of systems, and "any models that attempt to define its dynamic nature must also be able to represent the diversity of those elements."

As of today, there are strong societal, industrial, and political drivers for smart cities to happen — *why are investments not flowing on a large scale yet*? This article looks into why this is the case and proposes a self-sustainable model, which helps to bootstrap the smart city market. To this end, we first review the barriers to entry, which limit the smart cities ecosystem development. Thereupon, we propose a viable approach to scale business within said ecosystem. We then describe a high-level model that exemplifies a self-sustainable way to base cities' economies based on smart city infrastructures.

SMART CITY BARRIERS TO ENTRY

Although there are obvious factors that justify the introduction of smart cities, they are not really taking off and not truly realizing the projected potentials. The need for affordable housing, traffic congestion, the rising energy costs, water scarcity, and environmental targets or regulations are strong enough reasons to justify the concept's introduction.

However, the need for policy changes, limited capital availability, and piecemeal funding structures are preventing investment in smart cities. In addition, there are political uncertainties, which do not create a favorable environment for public and private investment. For example, the absence of long-term stability of carbon prices or the lack of public incentives for low carbon ini-

0163-6804/13/$25.00 © 2013 IEEE

tiatives makes investment in low carbon technologies unattractive. Moreover, the inconsistency in international, national, and regional rules and regulations related to environmental policies does not help to scale initiatives. Finally, there is a lack of appropriate and systematic methodologies and metrics for reporting and verifying the investment returns due to smart city technologies [5]. The actual economic context is also not helping the introduction of the smart cities context. Depleted public finances from the recession are slowing down public investments. The financial situation, the unavailability of credit, and the new pressures and regulations on financial institutions to reduce risk exposure by building stronger deposit bases are limiting the available cash flows, slowing down private investments.

Moreover, there are few alternative secondary markets to finance large smart city projects. Up to now, only grants coming from European Union (EU) funds or small local initiatives and local philanthropic capital allowed first trials to be run [6]. Barriers to entry are not only economic or political [7]. The geographical dispersion of the ongoing smart city projects, and the multiple and complex technologies involved and their small size are not helping to create the required critical mass that might help show the viability of smart city deployments. The latter is seen as an increased risk to investors, who find it risky and difficult to aggregate individual and small-scale projects into large-scale investment vehicles. All of the above translates into a certain immaturity of the market as viewed from the private sector, which in turn is enhanced by the complexity of relationships with the public sector.

Bootstrapping Smart City Initiatives

As stated above, there are political, financial, and technological barriers that need to be superseded to facilitate the introduction of the smart city business. Setting growth beyond organic growth rates has three dimensions today:

- A political dimension, calling for an establishment of smart city departments
- Establishment of transversal and interoperable technological platforms to manage the huge amounts of data generated
- A financial dimension, calling for a coherent self-sustainable business model [8]

Under the political dimension, historically, interactions between the private sector and the smart cities ecosystem have been fairly complicated, particularly in European cities, which have grown over centuries. One often observes that when it comes to decision making, ownership, decision making, and responsibilities are heavily intertwined. In the best of the cases, this hinders smart city deployments, and often even prevents key players talking to each other at all.

It has hence become clear that the entire decision and execution process within smart cities needs to be institutionalized, and many cities have indeed commenced forming their own "smart city departments" with their own decision making infrastructure and procurement processes. This development bears similarities with what occurred a few decades back when, with the occurrence of the first computers, IT departments slowly emerged. Indeed, while it may have been very political back then, the choice of a specific computer within a city hall today to facilitate better management is under the sole auspices of the IT department and not questioned at all by the running office. Smart city (SC) departments are, compared to IT departments, still far from this obvious modus operandi.

We thus observe that a first important issue toward sustainable smart city development is an independent SC department (or equivalent), which clearly decouples the political element of the improved city servicing from the underlying technologies and old-fashioned procurement processes. Notably, formal relationships can be impeded by the complexity of public sector procurement regimes, which are simply not adapted to new technologies, and hence are too expensive and time-consuming for the new ecosystem of high technology companies (sometimes very small) to engage with. By simplifying procurement practices and adapting those to, for example, servicing models based on quantifiable metrics, the level of engagement between cities and private ecosystem could be increased.

Although local entrepreneurs, small to medium enterprises (SMEs), and innovators have brilliant ideas and marketable technologies, they often have limited resources. On their own, they are not able to implement smart city infrastructures such as as water saving systems, lighting control systems or real-time transport information systems. But collectively, if the SC department takes into account their ideas and involves stakeholder groups in defining the business case, it may be that the local authority, a utility, or both may invest in such infrastructures.

Thus, utilities will definitively play an important role in the smart cities uptake. Generally, they will offer smart city services using some ICT infrastructure, which ought to be optimized for resource distribution, prevention of resource outages, easy and rapid maintenance actions, and so on. Sustainable smart city approaches ought to simplify and accelerate service delivery, thus reducing the operational cost and also enhancing the return on investment in a shorter period of time. Being in continuous interaction with the customers, they will provide customized services for customer-specific needs and preferences. By engaging utilities, entrepreneurs and the public sector attract a portfolio of potential innovations, and outcomes can be created to demonstrate the value of such investments.

Over the last couple of years, key industry and service sectors have been taking part in the industrialization of IT in the form of cloud computing and open service delivery platforms [7, 9, 10]. Moreover, the idea of conglomeration of services as a goal that requires the generation of transversal platforms to manage the multiple services involved in the smart cities ecosystem has been evolving. In the past years, new ecosystems of startups that provide innovative services and deliver new applications and solutions for different smart city areas have been emerging

Utilities will definitively play an important role in the smart cities uptake. Generally, they will offer smart city services using some ICT infrastructure, which ought to be optimized for resource distribution, prevention of resource outages, easy and rapid maintenance actions, and so on.

Building on top and strengthening this ecosystem will strongly influence the deployment of smart city infrastructures and services. This triggered Cisco, IBM, Telefonica and other global ICT players to have launched their respective smart city platforms in order to integrate their own and 3rd party services.

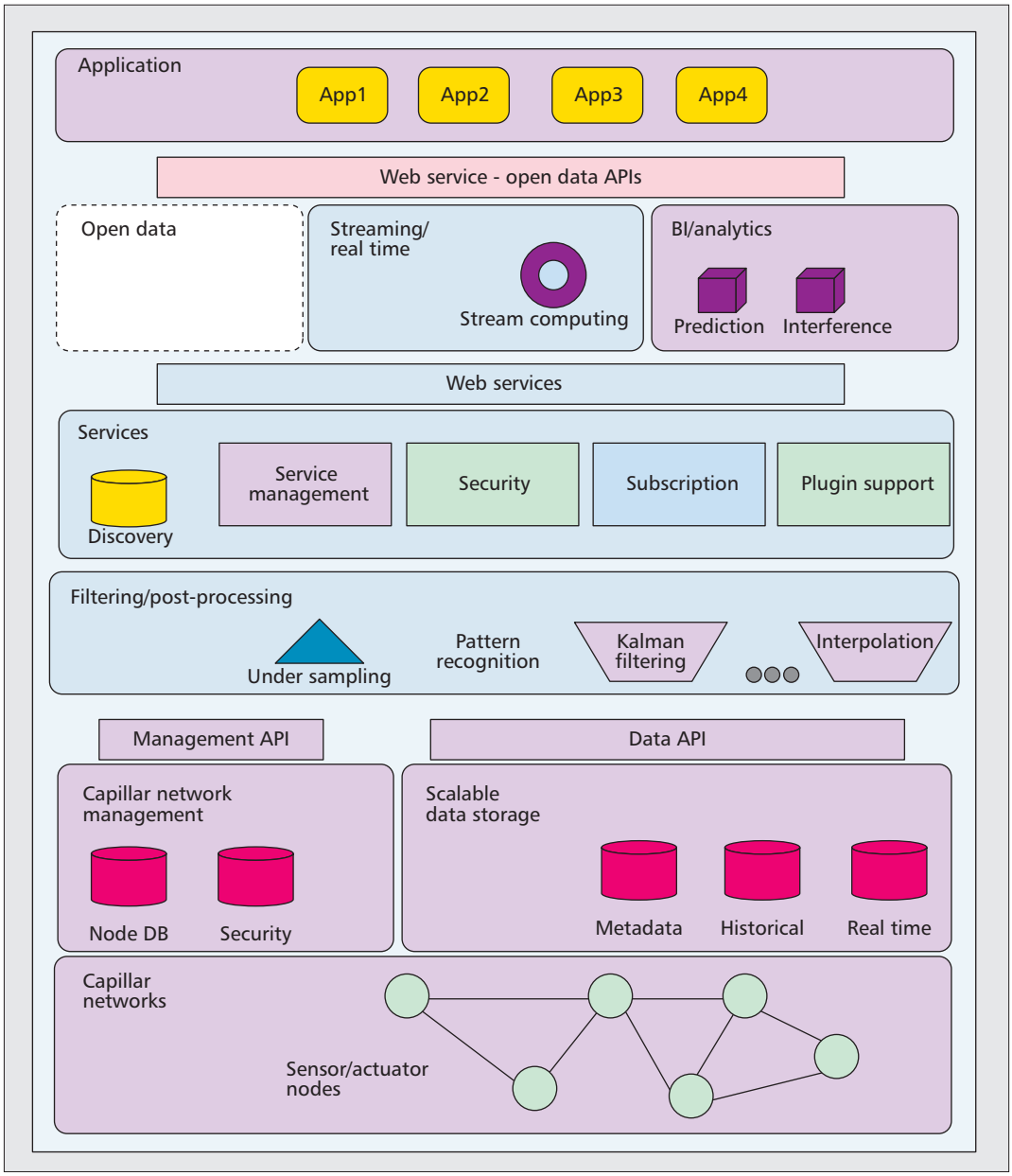

Figure 1. *Generic platform showing the main components to support heterogeneous smart city applications.*

[11, 12]. Building on top of and strengthening this ecosystem will strongly influence the deployment of smart city infrastructures and services. This has triggered Cisco, IBM, Telefonica, and other global ICT players to launch their respective smart city platforms in order to integrate their own and third party services [7].

From a generalist point of view, all the existing platforms offer similar characteristics. They offer seamless interconnection with monitoring systems at the infrastructure level. On top, there emerge big data structures allowing for storing and analyzing the generated information, which is eventually offered to third parties through standardized interfaces in an open data fashion. In Fig. 1, the general architecture with most of the available platforms is depicted.

Smart city platforms [13, 14] are designed to provide and agglutinate heterogeneous services to support a variety of application domains as shown in Fig. 1. A capillary network layer is composed of sensor nodes, actuators, software components, and other devices that gather data from (or actuate on) the city infrastructures and citizens. To deal with the data generated by the individual utility provider capillary networks, a generic middleware providing both control and data management planes is usually proposed. The data management plane provides massive raw data storage for historical datasets as well as real-time data storage to support stream computing applications [15]; this is decoupled from data filtering rules and post-processing, and interfaced by a generic service layer providing access, management, orchestration, and security services over the data. The control plane provides a well defined application programming interface (API) to manage the underlying capillary network infrastructures as well as the middleware components and configuration. More

general services are built on top of the basic core services provided by the middleware. This second layer of services offers big data management services related to the smart city domain. The latter include analytic services and prediction engines, real-time and streaming interfaces, and standardized open data APIs exposed as web services.

Concerning the financial dimension, it is possibly the biggest factor preventing meaningful smart city deployments. Importantly, no clear business models exist; only recently, [5] proposed a suitable platform to successfully evaluate the business models of new services offered by cities. However, the situation has further sharpened with the latest global economical downturn. Funding needs to be drawn from the scarce range of sources for smart cities to bloom; policy makers, technology and service companies, investors, and utilities alike wonder how to get this market going. The smart city market, in the sense of instrumenting, interconnecting, and making it more intelligent, clearly has enormous potential but, as of today, is a zero billion dollar market.

Digging a little deeper, however, we were able to understand that some domains of the smart city market were very hesitant, while others are currently flourishing [6]. If organized well, the scarce public funding can be used to unleash private and philanthropic investments. However, access to funding requires a creative articulation of value cases using metrics that demonstrate social, economic, and political value [5]. Without going into too many economic, historical, or strategic details, we advocate three clearly defined stages for the deployment of smart city technologies and services:

- The first phase ought to be dedicated to technologies and services that not only offer utility (in the sense that they are of great use and make urban living truly smarter) but also offer very clear return on investment (ideally after a very short break-even time). This phase is of utmost importance, since it essentially sets the technological basis (introducing the developed platforms described above) and guarantees viable bootstrapping of the smart city market by generating cash flows for new investments.
- The second phase has the scope of ramping up technologies and services requiring large upfront investments, showing longer return on investment periods or not necessarily producing direct financial gains, but maybe just of great use (or yielding second-order revenues). These technologies and services are expected to be attracted by the finances generated in the first phase, which will attract private capital, and take advantage of previously deployed infrastructures to lower its barriers to entry (i.e., platforms).
- The third phase relies on data availability through standardized APIs offered by the implemented platforms. Multiple services might then be offered by third party developers. This phase has the scope of making the system self-sustainable by developing services on top of the existing smart cities infrastructures and involving the whole value chain (through standardized APIs). This might produce a new tertiary sector exploiting data generated in the existing infrastructures, which will be used to offer new services to cities, utilities, and citizens.

We thus observe that a second important issue toward sustainable smart city development is a coherent three-phase smart city introduction, where:

- In the bootstrap phase, services are offered that yield utility and revenues, and set the basis for future developments (i.e., generic platforms, capillary networks).
- In the growth phase, previously deployed services generate cash to trigger new investments, which will turn into new services showing higher barriers to entry.
- In the wide adoption phase, services are offered by all stakeholders taking advantage of the existing infrastructures independent of offering revenues, utility, or fun.

Feedback Model: Data and Revenue Flows

In Fig. 2, the value chain and the different stakeholders in smart city deployment are presented. At the bottom of the chain are cities and citizens as prime enablers but also prime consumers of the generated services. Citizens as consumers enjoy various smart services provided by utility companies and city authorities, which aim to enhance their life in terms of security (e.g., better street lighting, smart parking guidance services, prevention of mucky corners), health and well being (e.g., reduced CO_2 emission), and economics (e.g., resource optimization).

Today, around 80 percent of European citizens live in urban areas at a very high density. Cities have to sustain the growth of population, and the consequent strain on utility providers and services that are necessary to facilitate daily life. Cities own the prime infrastructures that utilities operate. Internet of Things (IoT) devices and capillary networks are becoming essential technologies to monitor and control infrastructures operated by utility providers for improving daily operations and service delivery. This is attracting IoT device manufacturers and third party developers to take part in new sensing and communicating device developments. Often, IoT device manufacturers are startups offering vertical solutions targeting very specific problems (e.g., Smart Parking [11]). They usually evangelize the corresponding departments from different city halls but also utilities who are, in most cases, their potential customers. Utilities build their transversal platforms on top of multiple services. They offer middleware solutions that integrate multiple solutions with the goal of better service delivery and cost reduction.

As seen above, middleware solutions offer standardized APIs to interact with the data in an open data fashion.

As for today, we still see a certain immaturity in open data delivery, especially when articulated by the public sector. They have neither the necessary departments nor the necessary expertise to deliver data services. Therefore, we see that corporations or public-private partnerships (PPPs), acting as IoT service operators, will handle the delivery of new open data interfaces in a

The situation has further sharpened with latest global economical downturn. Funding needs to be drawn from the scarce range of sources for Smart Cities to bloom, policy makers, technology and service companies, investors and utilities alike wonder how to get this market going.

Citizens become the prime users and consumers, but participate as developers given a new market place is created. Utilities and operators benefit from data consumption and services consumption. Citizens thus improve their quality of live given a very dynamic service provisioning system.

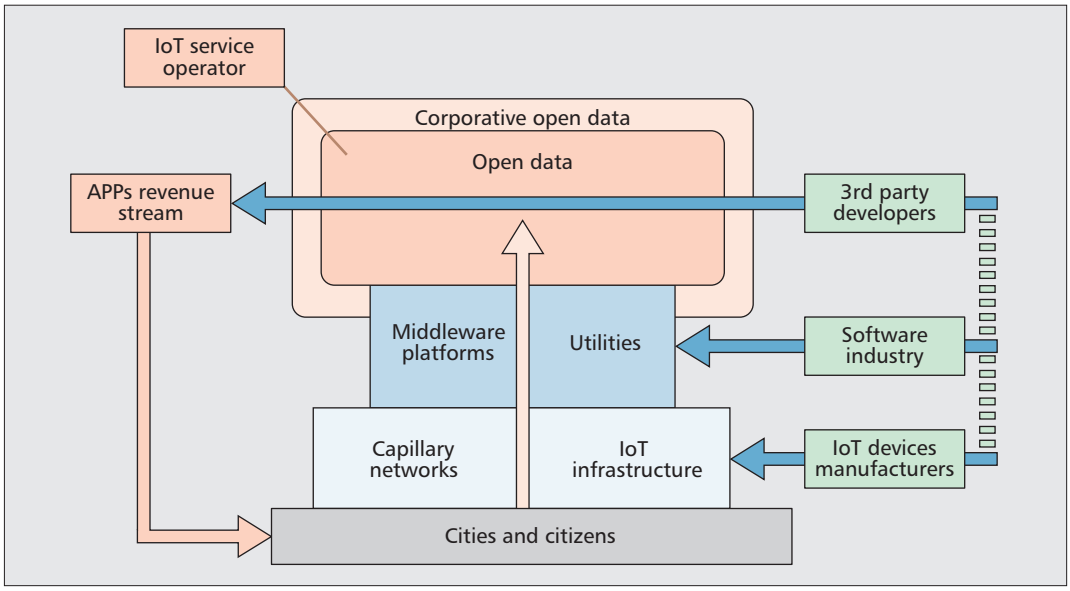

Figure 2. *Representation of the value chain and involved stakeholders in a three-phase smart city deployment.*

corporate fashion. In that process, utilities and operators but also SMEs play a crucial role. We believe that the API delivery process will be articulated similar to the markets and app stores that dominate the smart phone app scene. We thus define the new concept of API stores as platforms delivering standardized APIs to interact with the smart city infrastructure. Thus, the delivery of open data interfaces will be regulated as apps markets. The delivery of the information generated at the infrastructure level to third parties will be handled by corporations/PPPs who will grant access to utilities' data following different approaches linked to different business models:

App-store-like model: Upon developer subscription (which might involve some subscription fee), a set of verified APIs that grants access to useful data is delivered to the developer. Developers build their apps, analytic tools, and services taking advantage of the delivered information. The developed apps most likely will end up in Apple and/or Android app markets. IoT operators may want to capture a small percentage of the app sales in these markets. This will bring high-quality smart city services and apps into the mobile apps revenue stream. Developers will have the advantage of their app being automatically valid for all the cities running under the same IoT operator, and processes to ensure the quality and security of the apps will be in place.

Google-Maps-like model: Some of the developed services may only make sense if the granularity, reliability, and authenticity of the provided information through the API store is high enough (e.g., traffic information). Thus, the percentage fee on the apps sales price will be scaled according to the granularity of the queries made to the API. Apps with low numbers of queries will end up being free, which will help ramp up the introduction of new services.

Open data model: Some cities may want to grant access to some of the data as a classical open data vision, without charging any fee to developers.

One side effect of this model is that IoT operators/utilities/PPPs will have to update and maintain their APIs, constantly offering new access to new capillary networks and fostering interaction among the generated services. The latter will trigger closer interactions with IoT device developers, solution developers, and service providers.

The regulated delivery of information will ensure, on one hand, quality of service provisioning, and avoid fraudulent use or abuse of open data information. Moreover, the regulation by specific departments and the promising business model behind it will ensure market persistence, support, political independence, and standardization. Utilities running services on different municipalities will benefit from the new services developed by third parties, capturing part of the sales market. Freelance developers, SMEs, and third parties will also have opportunities to develop new analytics tools, new services, and new devices.

Citizens and cities will also benefit from this structure. First of all, a new marketplace will be created. Freelance developers, apps developers, and SMEs will benefit from standardized and regulated access to the data with the advantage of not having to directly deal with public regulators or utilities. Cities will benefit from a new marketplace at the top of the value chain, which will attract new talent, which in turn will generate new services that will have an impact on citizens' quality of life. Utilities/service providers, apart from the operational benefits of better operating of their infrastructures, will get into a new market by capturing a small amount of the crowd-sourced services developed.

As seen in Fig. 2, the introduction of the smart city concept offers multiple opportunities for new and existing businesses through innovative business models and a structured value chain. We have also observed that smart city deployment complexity is twofold: on one hand,

the scarcity of resources to trigger infrastructural investments; and, on the other hand, scaling the model up and making it self-sustainable. We have proposed three steps to reduce the entry barriers, and we suggest a model that will help to scale up smart cities deployments, generating a feedback model involving citizens and developers as well as utilities and operators.

If we carefully look at the established relations between the different stakeholders in the model presented above, we observe that corporate open data services, likely regulated through public-private partnerships, constitute a basic element to benefit all the stakeholders in a smart city deployment. For illustrative purposes, in Fig. 3, the different interactions between the different stakeholders involved in a city are presented.

The interaction between smart device developers and industry is crucial for feeding information to corporate open data platforms. Industry will pay for the sensing and actuating infrastructure but benefit from the data generated. Industry will push smart sensor device developers to create new and better solutions.

Developers from regulated and standardized interfaces (API stores) will be able to develop new services and analytic tools that will be used by citizens through the classical Android and Apple markets. Revenue sharing models have proven to be successful in the smart phone scene; we thus believe that this will also be applicable to the smart city scenario.

Citizens become the prime users and consumers, but participate as developers when a new marketplace is created. Utilities and operators benefit from data consumption and services consumption. Citizens thus improve their quality of life given a very dynamic service provisioning system.

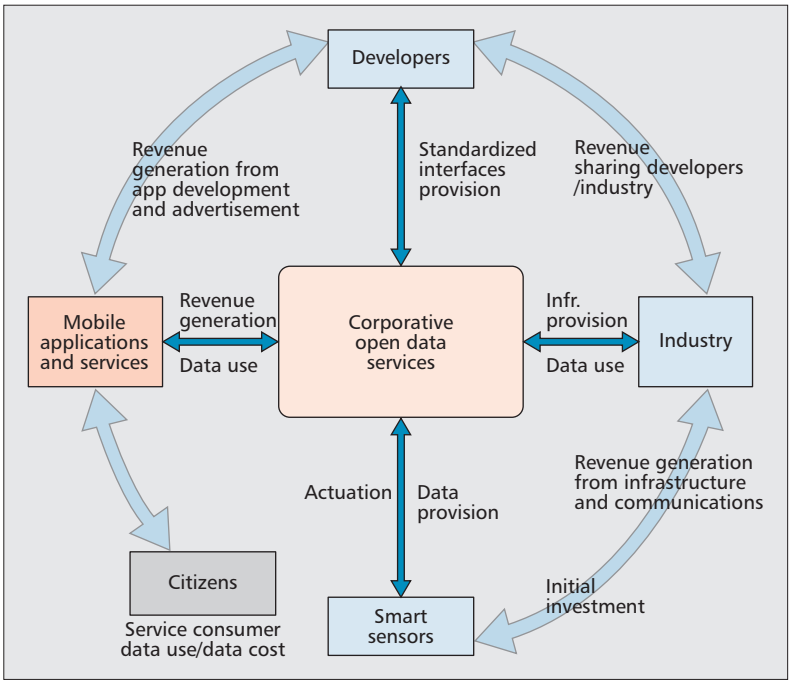

Figure 3. *Representation of the data flows and relations among the stakeholders in the corporate open data services framework.*

Conclusions

With the majority of today's civilization living in cities, problems are prone to increase, and thus solutions are urgently needed. Compelled by this necessity, city halls and political decision makers have become very alert, with small and large technology companies alike hoping to jump on the smart city wagon of the 21st century.

This is for good reason, since the smart city market is estimated to be of hundreds of billions of dollars by 2020. While we have a clear idea today of the necessity, usefulness, and business case of smart cities, business around smart cities is having difficulty taking off. We have therefore looked into why this is the case and proposed a clear roadmap to help the ecosystem grow.

To this end, we first suggest viable steps forward toward the introduction of the smart city concept by means of a three-phase rollout. In the first phase, we advocate the deployment of reliable sensing infrastructure able to degenerate authenticable but, most important, monetizable real-time data streams, which essentially bootstraps the smart city market. In the second and third phases, the use of not necessarily monetizable reliable and crowd-sourced data is facilitated.

Based on our first-hand experience, we then dwell in greater depth on the data flow and data revenue models. We show that big data is indeed a promising field for exploitation. We introduce the concepts of app store data flow models where developers use data APIs to generate applications that are of use to smart city stakeholders (i.e., cities, citizens, utilities, SMEs, etc.). We also advocate the use of Google-Maps-like approaches where reliable and authenticated data is available, likely against a license fee. Finally, the completely open data model will also have its place, more so if subsidized by public authorities; however, we believe it will not survive on a "free-for-all" and voluntary basis.

Acknowledgments

This research is supported by the FP7-Calipso European project (FP7-ICT-2011.1.3, PN: 288879) and the Future Internet-Public Private Partnership (FI-PPP) European project Outsmart (PN: 285038) under the 7th Framework Programme FP7-2011-ICT-FI. Albert Angles and Marc Domingo-Prieto are funded by the Generalitat de Catalunya under the TALENT Empresa grant. Xavier Vilajosana is funded by the Spanish Ministry of Education under a Fullbright-BE grant (INF-2010-0319). Borja Martinez is funded under grant Inncorpora-TU-1558 from the Ministry of Industry. Jordi Llosa is funded under the Torres Quevedo Program PTQ-10-03987.

References

[1] U.N. Population Fund (UNFPA), "State of World Population 2007, Unleashing the Potential of Urban Growth," online report, 2007, http://www.unfpa.org/public/publications/pid/408

[2] M. Kinver, "The Challenges Facing an Urban World," BBC News website, online article, 13 June 2006, http://news.bbc.co.uk/2/hi/science/nature/5054052.stm.

[3] M. Kinver, "UN Report: Cities Ignore Climate Change at Their Peril," BBC News website, online article, 29 Mar. 2011, http://www.bbc.co.uk/news/science-environment-12881779.

[4] Pike Research, "Smart Cities. Intelligent Information and Communications Technology Infrastructure in the Government, Buildings, Transport, and Utility Domains," online report, 2011, http://www.navigantresearch.com/research/smart-cities.
[5] N. Walravens and P. Ballon, "Platform Business Models for Smart Cities: From Control and Value to Governance and Public Value," Feature Topic on Smart Cities, *IEEE Commun. Mag.*, this issue.
[6] R. Robinson and W. Webb, "What's So Clever About Smart Cities?," *Ingenia Online Mag.*, The Royal Academia of Engineering, issue 50, Mar 2012.
[7] C. Mulligan and M. Olsson, "Architectural Implications of Smart City Business Models: An Evolutionary Perspective," special issue on Smart Cities, *IEEE Commun. Mag.*, this issue.
[8] M. Dohler *et al.*, "Smart Cities: An Action Plan," Barcelona Smart Cities Congress 2011, Barcelona, Spain, Nov.–Dec. 2011.
[9] EU Project, "OUTSMART — Provisioning of Urban/Regional Smart Services and Business Models Enabled by the Future Internet," Future Internet – Public Private Partnership (FI-PPP), Apr. 2011–Mar. 2013, http://www.fi-ppp-outsmart.eu/
[10] EU Project, "FI-Ware. Future Internet Core Platform," Future Internet — Public Private Partnership (FI-PPP), Apr. 2011–Mar. 2014, http://www.fi-ware.eu/
[11] Worldsensing, "Smart City Solutions Startup," company web page, 2008, http://www.worldsensing.com.
[12] BitCarrier Co., "Smart City Solutions Startup," company web page, 2006, http://www.bitcarrier.com.
[13] P. Fritz, M. Kehoe and J. Kwan, "IBM Smarter City Solutions on Cloud," White Paper, 2012, http://www-01.ibm.com/software/industry/smartercities-on-cloud.
[14] J. Hogan *et al.*, "Using Standards to Enable the Transformation to Smarter Cities," *IBM J. Research and Development*, vol. 55, no. 1.2, Jan.–Mar. 2011, pp. 4:1–4:10.
[15] A. Biem *et al.*, "IBM Infosphere Streams for Scalable, Real-Time, Intelligent Transportation Services," *Proc. SIGMOD '10*, 2010, pp. 1093–104.

BIOGRAPHIES

IGNASI VILAJOSANA (ivilajosana@worldsensing.com) is the CEO of Worldsensing, a company specializing in state-of-the-art industrial wireless sensor networking solutions. Worldsensing's products are tailored to provide unprecedented and innovative solutions to the smart cities, smart infrastructures, and smart fields markets. Prior to Worldsensing, he obtained a Ph.D. in physics in 2008. During his academic life he was the author of more than 30 high impact publications in the geophysical and instrumentation fields. He was a visiting researcher at the Norwegian Geotechnical Institute, Oslo, in 2007 and to the Swiss Federal Institute For Snow and Avalanche Research, Davos, Switzerland, in 2008. He also holds a part-time professorship at the Politechnical University of Catalonia (UPC). Recently he has received appropriate business training to lead Worldsensing's commercial activities.

XAVIER VILAJOSANA [M] (xvilajosana@worldsensing.com) is an associate professor at the Universitat Oberta de Catalunya (UOC) in the area of computer networks and distributed systems. He is also chief innovations officer and co-founder of Worldsensing, and currently a Fullbright visiting professor at the University of California (UC), Berkeley. During 2008 he was a visiting researcher at France Telecom Labs, Paris, and in early 2009 he received his Ph.D. in computer sciences from UOC. He is co-leading the development of the OpenWSN project at UC Berkeley, an open-source initiative to promote the use of fully standards-based protocol stacks in M2M applications. During the last years of research he has acquired extensive experience in distributed systems and wireless ad hoc networks. In the area of WSN he proposed several decentralized load balancing schemes for the RPL protocol, provided an open source implementation of it, and actively contributed to the IETF 6LowApp and 6TSCH working groups with the 6TUS adaptation layer on top of IEEE 802.15.4e. He holds a patent and has published several journal and conference papers, has contributed to two books, and participated in standardization activities. Xavier is a founding member of the IEEE Sensors Council in Spain. He has chaired or is chairing several prestigious international conferences and journals. His research interests include low-power communication protocols, routing, scheduling, and optimization problems in distributed systems at large.

JORDI LLOSA is co-founder of Worldsensing. He has an M.Sc. in computer sciences. He has in-depth experience in software, middleware, and hardware design, wireless sensor networks, and context-aware systems at large. He is an author of high impact publications and patents. Nowadays he is the chief technical officer at Worldsensing, leading the development of the Worldsensing products, and involved in the operations of the company.

BORJA MARTINEZ received his B.Sc. degree in physics in 2000 and in 2003 his B.Sc. degree in electronics engineering, both from the Universitat Autonoma de Barcelona (UAB), where in 2007 he also obtained his M.Sc. degree in microelectronics and electronics systems. From 2004 to 2010 he was a member of the Technology Transfer Group of the Microelectronis Department. During this period, he participated in several projects related to wireless smart devices. Thanks to working very closely with industry, he acquired a strong background in robust algorithm design and firmware implementation. Recently he started his Ph.D. on data compression techniques, focusing on methods specifically adapted to computational and power constraints of wireless sensor networks. In 2010 he joined WordSensing with the purpose of implementing developed algorithms in real scenarios. Since 2007 he has been an assistant professor at the High School of Engineering, UAB.

MARC DOMINGO-PRIETO is a Ph.D. student in security of wireless sensor networks at the Open University of Catalonia (UOC) as well as a firmware developer at WorldSensing. He holds a degree in computer systems and a Master's in computer architecture, networks, and systems from UPC. He collaborates with the K-ryptography and Information Security for Open Networks (KISON) research group at UOC. He has published several journal and conference papers, and has contributed to one book. His research interests include security in low-power communication protocols and peer-to-peer, scalable distributed algorithms, and energy-efficient applications.

ALBERT ANGLÉS holds a Ph.D. in telecommunications, specifically in the field of low-power wireless technologies. From 2010 to 2013 he was a researcher in the R&D department of WorldSensing, providing mutual feedback between the research and industrial worlds. He obtained his Master's degree in 2010 in design of telecommunication systems and his degree in telecommunications in 2008 provided by the UAB. From 2009 to 2010 he was a member of the Signal Processing Communications and Navigation Group at the univerity. During this time, he carried out research tasks focused on tracking and positioning techniques for traffic applications based on wireless sensor networks. Additionally, he developed a tracking simulator under an urban environment and validated his tracking algorithm with an experimental campaign. From 2007 to 2008 he was a member of the same research group. During this time, he focused on evaluating and comparing wireless broadband technologies (IEEE 802.16-2004 with IEEE 802.11a) as wireless local loop access solutions for rural environments. He has been published at a conference and in two journals, one accepted paper in press, and a paper currently under review. His research interests include antennas, wireless propagation, and routing for application in M2M solutions (WSN and RFID) and other kinds of wireless technologies.