Architectural Implications of Smart City Business Models: An Evolutionary Perspective

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ABSTRACT

Smart cities have rapidly become a hot topic within technology communities, and promise both improved delivery of services to end users and reduced environmental impact in an era of unprecedented urbanization. Both large high-tech companies and grassroots citizen-led initiatives have begun exploring the potential of these technologies. Significant barriers remain to the successful rollout and deployment of business models outlined for smart city applications and services, however. Most of these barriers pertain to an ongoing battle between two main schools of thought for system architecture, ICT and telecommunications, proposed for data management and service creation. Both of these system architectures represent a certain type of value chain and the legacy perspective of the respective players that wish to enter the smart city arena. Smart cities services, however, utilize components of both the ICT industry and mobile telecommunications industries, and do not benefit from the current binary perspective of system architecture. The business models suggested for the development of smart cities require a long-term strategic view of system architecture evolution. This article discusses the architectural evolution required to ensure that the rollout and deployment of smart city technologies is smooth through acknowledging and integrating the strengths of both the system architectures proposed.

INTRODUCTION

We are now a "city planet" [5]. As of 2007, 50 percent of the world's population was living in cities rather than rural areas [10]. Moreover, cities will continue to grow — it is predicted that 70 percent of the world's population will be living in cities by 2050. In addition to this fundamental shift in the organization of human society, we are also faced with increasing natural resource constraints, marked increases in population, and a restructuring of the global economy. Existing cities and the new ones that will be built will therefore need to handle massive tensions in three spheres simultaneously: environmental impact, economic growth, and social evolution.

Digital technologies are often suggested as the panacea for these issues through the development of "smart cities" — cities that integrate a digital infrastructure with the physical city in order to reduce environmental impact while improving quality of life and economic prospects. These sorts of concepts have been around for several decades, appearing as early as the 1980s [9]; however, the recent advent of smart phones and cheaper sensor technology means that digitally enabled, or "smart," cities are fast becoming a real-world possibility [7].

A multitude of "smart" solutions have become available over the last five years with several major information and communications technology (ICT) players (e.g., IBM,[1] Cisco,[2] and Intel) beginning to invest heavily in the marketing and technology solutions behind the creation of smart cities.

Many of the visions of smart cities from technology vendors are quite sterile, however, with the collation of massive data sets and their analysis allowing for the removal of the human from the decision making process — digital technologies are viewed as better decision makers than human beings. While this may be true in many scenarios, it is not necessarily the case for all of the use cases for smart cities. An approach is required that takes into account the multitude of technical architecture viewpoints. This article focuses on the system architecture evolution required in order deliver the innovative new "smart city" business models proposed within the city context.

CURRENT TECHNICAL PERSPECTIVES ON SMART CITY ARCHITECTURES

Several approaches to smart cities have been proposed — many of these technologies or solutions, however, are the re-application of systems and architectures traditionally implemented for enterprises and corporations. They are not designed for the unique problems that urban

[1] *http://www-03.ibm.com/innovation/us/thesmartercity/index_flash.html*

[2] *http://www.cisco.com/web/strategy/smart_connected_communities.html*

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environments face, and they are generally designed with efficiency in mind: quite often these technologies displace jobs, rather than create them. In contrast to enterprises, however, cities must use positive externalities associated with digital technologies to create new jobs and even new industries to replace those that have moved overseas. More important, however, is the lack of sensitivity to one foundational issue for cities: a city is nothing without the human beings that form its basis. Smart city technologies that do not take into account the role that the end user plays in capturing, delivering and generating data is unlikely to achieve widespread approval within a city's communities as understanding of data privacy and associated problems spread.

It is not just pure ICT companies, however, that wish to enter the smart city market, but also connectivity providers such as mobile telecommunications players; for example, Ericsson, Vodafone, Alcatel-Lucent, and others have also started marketing solutions designed specifically for the mobile network infrastructure. Mobile network operators, in contrast to pure ICT vendors, have a unique position within emerging smart city business models: control over individual end-user identities and subscriptions. Much of the proposed analysis of data within a smart city context is useless without the social context [4] of the data, however. A phone can only ever tell you its exact location; a human being can tell you that exact location is their place of employment and with whom they work. These approaches, therefore, while more closely aligned to individuals, still leave out one key architectural issue: how to include citizens in creating smart cities.

Urban Prototyping

Other approaches, in contrast to the top-down approaches of the mobile and ICT industries (e.g., Urban Prototyping),[3] attempt to link citizens directly into the development of smart city technologies and applications. Many of these initiatives have proven to be extremely popular and successful, and have developed far beyond a mere "hackathon" model — many are designed to also take into account the long-term economic sustainability of solutions that come out. A key problem for the output of such solutions, however, is achieving sufficient *scale* for longevity. In addition, these solutions often rely on existing infrastructure and work within the confines of the technical architectural boundaries defined by the datasets that are opened to developers in this manner. As a result, these bottom-up approaches do not currently execute significant control over the system architecture, although they do play an extremely important and significant role in one aspect of system architecture: pressuring government and other actors to deliver data in an open format, usable by developers for civic applications. Examples include the pressure exerted to ensure that Transport For London (TFL) opened its datasets to developers in London or the work done by the open data movement to get Ordnance Survey (OS) to deliver digital maps of the United Kingdom for free. Concepts such as urban prototyping, therefore, are set to take a larger role in the development of the architectural guidelines that smart cities follow.

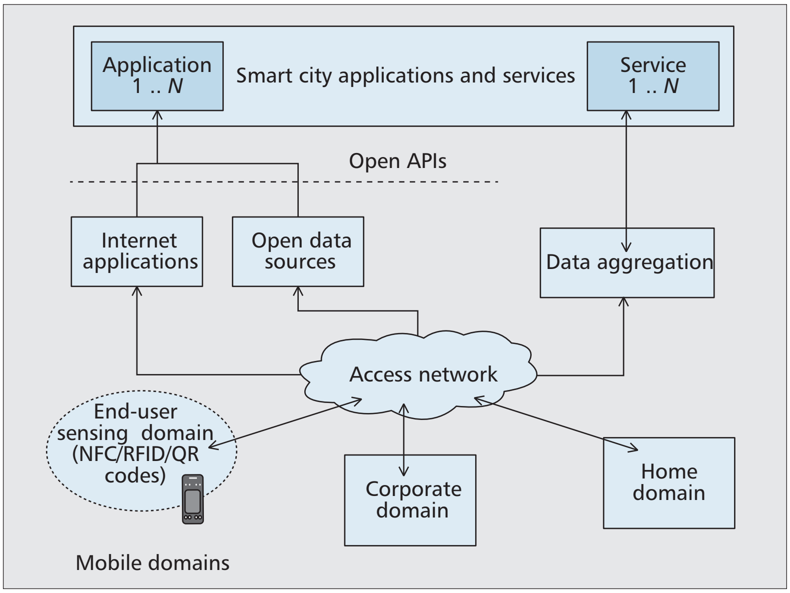

Figure 1. *A high-level overview of smart city architecture.*

The Human in the Smart City Architecture

A significant number of business models are being suggested for smart city applications and services that have as their basis "the ability to access much broader and bigger amounts of data, linked to the individuals and the society of which they are the fabric: for example Radio Frequency Identification (RFID) -based smartcards give a fine-grained picture of how public transport is being used" [4].

A key question for the architecture of any smart city solution must therefore be how to effectively link the human into the solution architectures for smart cities, while ensuring appropriate scale to keep costs low enough to create a smart city market. It is, however, the interaction between the human, the digital technology, and the city that forms the basis of any "smart city."

In the next section, we investigate the business models, and two main competing value chains and technical architectures proposed for smart cities related to the use of data and the creation of information products for sale or to generate improved decision-making [6, 7]. We then investigate some architectural implications highlighted by these business models and some potential solutions that can link these two architectures together as an evolutionary step to fully integrated smart city system architectures.

System Architectures for Smart Cities

Figure 1 illustrates a high-level system architecture for smart city applications and services, including some of the data sets that might be useful in the creation of useful services. This data may be formed of a number of different input sources, including but not limited to:

[3] *http://www.upsingapore.com/*

The system architecture of a solution captures value chain relationships within it and the power relationships within business models can shift rapidly as a result of relatively small technical changes.

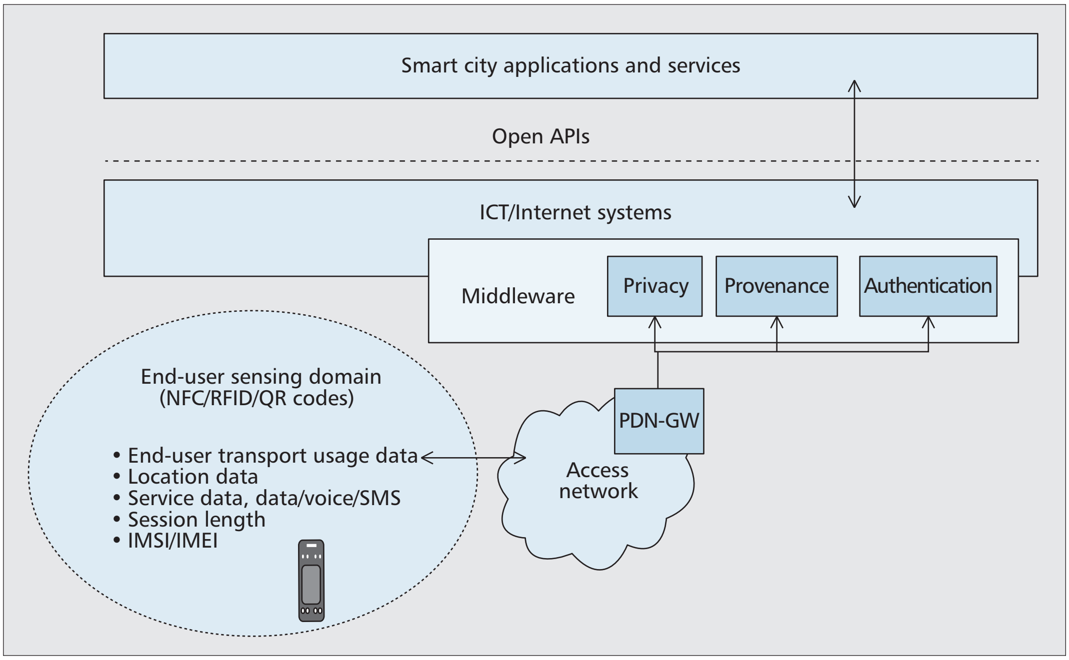

Figure 2. *Combining the system architectures of the mobile network and ICT networks while ensuring human decisions are included in the data aggregation process.*

- Data from smart meter technologies in the home (home domain)
- Data from smart grid technologies (within the corporate domain of a electricity operator)
- Data from citizens through interactions with mobile devices, near field communications (NFC) (e.g., Oyster cards), Internet applications (e.g., Twitter) (mobile domain)
- Data from the city or other government sources: maps, census data, police data, etc. (open data sources)
- Data from corporations: mobile operator networks, car manufacturers, or others (corporate domain)
- Internet applications such as Twitter and Facebook

Smart city services are often generated from the aggregation of large data streams and the associated creation of information products, which allow improved decision making for cities and citizens [7], for example, combining radio access technologies, sensors, smartphones, cloud computing and data analysis together to improve decision making. Figure 1 also highlights that there are two main system architectures that need to work together: mobile network architecture and ICT, or enterprise and Internet-based system architecture.

In order for smart city applications and services to be successfully rolled out, therefore, these two competing technical architectures need to find some common ground. In particular, this is necessary when it comes to protecting the data privacy of the end users who, unwittingly or not, are donating information to the development of these applications and services [1–4, 8].

Smart city applications must also be able to trust the data that is coming in for analysis and inclusion in the creation of an information product: a method to highlight the provenance of any data — that it has come from the end user it says it has without alteration — is therefore extremely important. Also, end users may not wish all of their data to be shared indiscriminately and used for the creation of certain types of information products. All of these issues imply the necessity to evolve system architectures for smart city contexts.

Business Models, Value Chains, and System Architecture

The business model, value chain, and system architecture of technology industries have evolved closely together since the 1960s [7]. The current evolution toward smart cities is indicative of yet another evolution of society and businesses to which technology and the associated technical architectures must respond. The system architecture of a solution captures value chain relationships within it, and the power relationships within business models can shift rapidly as a result of relatively small technical changes. Precursors to this evolution have already been seen with significant changes to both the business models and the technology architectures on mobile and Internet systems with the introduction of the iPhone and Android devices. In addition, devices and solutions originally designed for the ICT industry now have to interwork with telecommunications networks (e.g., connecting cloud computing to mobile networks). Telecom operators, meanwhile, wish to offer more innovative enterprise solutions than they do today. It is natural, therefore, that existing system architectures evolve to reflect new business models that are proposed.

The business models proposed for smart cities are no different: by their very nature they imply an evolution of the value chain and also

Category	Example	Technical impact
Environmental improvement	Smart meters, smart grid, air quality monitoring	New devices connected to network
Economic growth	Incubators, smart education, green growth initiatives	Open data, data aggregation
Cost efficiency	Removing data silos between government departments	Cloud computing, open data
Safety	Sensoring firemen, redirecting transport around a collision	New devices, new data sources, data aggregation, open data
Quality of life	Feedback loops in urban planning from data across the city	Data aggregation, information management
Connected citizens	Transport apps for a "connected commute"	Privacy, data aggregation, open data
New business models	Using data from smartphones across a city to create new advertising and revenue streams for local businesses	Privacy, data aggregation, open data, data provenance

Table 1. *Categories of smart city business models.*

the associated system architecture that underlies both these industries.

Example Business Models

The vast majority of business models within the smart city space fall into one of several categories, illustrated in Table 1.

Business models driven by the aggregation and analysis of end-user data, however, are often usable in many different scenarios. Take, for example, the data generated on a mobile network as an end user moves about the city. Table 2 illustrates some of the data collected by a mobile operator during a voice session, while Table 3 illustrates the type of data gathered during a packet data session:

This data can be used in conjunction with other data sets, such as the location of billboards used by an advertising agency. Using the density information gleaned from the mobile network data (number of end users around a particular billboard at one time, what services they are using on their phones and for how long), a new pricing structure for those billboards could be developed.

While this is a purely commercial application of the end-user data in question, the same data could be used by a city to generate tailored public service announcements for end users. Every business model that touches on the interaction of human beings with the physical infrastructure of the city raises a question for both the regulatory environment and also the technical architecture implemented: What is the boundary between the private and public good when it comes to information captured within smart cities?

Implications for System Architecture

As discussed in the previous section, smart city business models create both new opportunities, but also new challenges for the telecom and ICT players, and city leadership. This section highlights some of the architectural impacts of the smart city business models proposed.

Data	Description
Service type	Voice call, video call, SMS, etc.
Call start time	Start time of call
Disconnect time	End time of call
Call direction	Incoming/outgoing
Location at call initiation	Approximate location of caller
Location at call end	Approximate location of caller

Table 2. *Voice session (circuit switched) data.*

New Devices

A multitude of new devices will need to be connected to both mobile and fixed networks. These include not just sensors and actuators, which generate large amounts of data *in aggregate*, but also connecting devices such as closed circuit television (CCTV) that generate large amounts of streaming data continuously. Networks must therefore evolve to handle the multiple devices that send small amounts of data rather infrequently. On an aggregate level, however, this means potentially that the number of devices, multiplied by even a small amount of data, induce a very high load on the network.

A key network architecture impact of these devices is the management of *peak loads*. For example, if there is a blackout, a network may be overloaded by smart meters all reporting simultaneously when electricity is resumed. This, however, needs to be managed by the owner of the network to ensure that service delivery is maintained. In addition, for mobile operators, these devices cause another issue: sensors tend to use signaling quite often, for which operators do not currently charge, but send very little data, which is where operators have generally earned their revenues. Further discussion of handling of peak loads is covered by Hossain elsewhere in this issue.

Data	Description
Served IMSI	GSM Subscriber IMSI
PDP context start time	Start time for packet service
PDP context end time	End time for packet service
Total GGSN uplink traffic data volume	Data uploaded (to network)
Total GGSN downlink traffic data volume	Data downloaded (to phone)
Location at session initiation	Approximate location of caller
Location at session end	Approximate location of caller

Table 3. *Data gathered during a packet data session.*

While these new devices can often be the focus of much technical discussion, an equally important aspect for architectural evolution is the new behaviors for devices on networks (e.g., the connected citizen or consumer).

Connected Citizens

As illustrated by Walraveens (elsewhere in this issue), many of the new business models relate to the use of consumer connected electronics. Today, these mainly refer to the use of smart phones, but a plethora of consumer devices are now starting to be connected and used in smart city applications. Examples include e-readers, GPS, and connected cameras. In addition, new software and hardware are being integrated into consumer devices all the time. For example, "perceptual computing" software development kits (SDKs) that allow devices to "read" the facial expressions of their users are emerging and starting to be embedded into mobile devices. These technologies will allow for new business models to be created around smart cities; for example, a connected camera could be used to send images of a poorly repaired road in a local neighborhood, or an application could "read" the emotional responses of end users when they are in particular areas of the city.

Such devices change the nature of the interaction between the networks and consumer electronics. For example, smart phones have applications that act even without human triggers (e.g., downloading emails or apps that report location to remote servers). Networks were traditionally dimensioned for end users actively using a mobile phone through SMS or phone calls or web browsing. Networks will need to be able to cope with applications that frequently access the network in order to synchronize data or keep firewalls open.

End-User Privacy, Data Provenance, and Data Monopolies

Many services on the web may be viewed as data monopolies, entities that capture significant amounts of end-user data in exchange for a "free" service. End users across the globe are, in essence, working for free, adding revenue to corporations such as Facebook, Google, and many others. Moreover, there is an argument that states the data relevant to smart city applications should not be monopolized, but rather made available as a public good for civic improvement.

In addition to issues of monopoly, the use of data that can potentially identify individuals raises multiple privacy and civil rights issues. As a result, several solutions have been developed that "rather than locking data in the hand of a service provider" allow users to "retain ownership of the data and control who to share it with" [4].

As mentioned, the role of the human and their interaction with smart city technologies in different contexts is the foundation of many proposed business models. While this data is useful to collect, protection of end-user privacy is important, as are data provenance and tagging of data so that end users can indicate how they wish it to be used (whether they will permit the data to be used to generate an information product for use by marketers, etc.) Protecting end-user data and data gathered from sensors not owned by the city in question are therefore a key question for the rollout of smart city technologies. Rather than taking a purely technical view of this, a value chain perspective is useful to follow as it allows for the identification of business interests across the industry, rather than focusing solely on one form of technology solution. With regard to privacy, an important question is, who has an incentive to protect the privacy of end-user data today? Privacy issues were covered in more detail by Martinez in last month's issue of this magazine.

Figure 2 illustrates a possible network architecture, which combines the benefits of the mobile network architecture with the principles of data privacy, provenance, and authentication mechanisms.

In addition, an end user could theoretically tag their data transmissions with different privacy settings from his or her terminal. This would provide three things:

- Assurance to third-party servers that the data from the mobile network is actually from whom it says it is through the mobile network authentication and authorization mechanisms.
- A provenance trail for the data for third parties from the device/subscription.
- End users could also tag that they do not wish this data to be aggregated, sold, or in any other way reused in the creation of an information product. This would also apply for sensor/NFC/RFID solutions that the owners wanted to ensure that they were sharing data with some applications for, say, compliance with regulatory requirements, but not, through information products, with their competitors.

Recommendations

Further study is required to understand how to better link the architectural views of the ICT and telecommunications networks in order to ensure that end users are provided the best service. This will help generate trust within the smart city systems, with end users given direct control over their data streams, enabling both top-down and bottom-up approaches to civic engagement.

- Regulatory frameworks with regard to smart city data need to be re-assessed from the context of how it can potentially be used to create a public good that is delivered to all as well as make personal data available for sale. Such regulation should focus on data that can , for example, improve quality of life in a city, or reduce the environmental impact of denser populations in cities.
- Architectural solutions that prevent the creation of data monopolies need to be investigated and regulated.
- There is a business incentive for operators to participate in the frameworks for privacy (e.g., protecting their subscribers data); however, there is a lack of technical solutions that link the mobile operator network together with the Internet players in this space. There is benefit for both parties to work together to address this, as it will create a larger overall market for smart cities.
- Finally, the role of the human being within the creation of a smart city cannot be overlooked in favor of solely large-scale data analysis. A city does not exist without its inhabitants, and the technical architectures for such applications and services need to properly reflect this. Addressing privacy, data provenance, and traffic marking are only the first steps in the architectural evolution.

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Biographies

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