RESEARCH ARTICLE

Smart cities and cloud computing: lessons from the STORM CLOUDS experiment

Christina Kakderi*, Nicos Komninos and Panagiotis Tsarchopoulos
URENIO Research, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece

Abstract: Since the emergence of cloud computing paradigm, there has been an increasing interest on the adoption of cloud computing from municipalities and city governments towards their effort to address complex urban problems. This paper explores the significant role that cloud computing can play in helping cities on their way to become smart. We focus on the STORM CLOUDS paradigm as a solution for municipalities everywhere in order to (i) deploy a portfolio of smart cities applications related to governance, economy and quality of life on a single cloud-based platform and (ii) use the platform and its accompanied tools to migrate their existing applications to the cloud environment. Besides the conclusions from the STORM experience, the paper closes with a number of research trends and future challenges that are expected to define the adoption of cloud computing from municipalities and city governments in the following years.

Keywords: smart cities, cloud computing, cloud platform, portfolio of cloud-based services, applications' migration

*Correspondence to: Christina Kakderi, URENIO Research, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece; Email: christina@urenio.org

Received: February 10, 2016; **Accepted:** April 29, 2016; **Published Online:** May 10, 2016

Citation: Kakderi C, Komninos N and Tsarchopoulos P, 2016, Smart cities and cloud computing: lessons from the STORM CLOUDS experiment. *Journal of Smart Cities*, vol.2(1): 4–13. http://dx.doi.org/10.18063/JSC.2016.01.002.

1. Introduction

Cloud computing has emerged during the last years as a disruptive model, with the ability to transform IT organisations, helping them to become more responsive and agile than ever before. Due to its multiple and significant benefits, cloud computing can particularly help complex organisations such as cities run more efficiently, providing new opportunities and opening up new business models. Although clearly at an early stage, the discussion on how cloud computing can help cities towards their effort of becoming smart has revealed a plethora of applications regardless of the size and level of organisation, and wealth of a city. The paper aims to contribute to this discourse both at the theoretical and empirical level, firstly, by reviewing the literature on the cloud computing paradigm and the way smart cities can benefit from it, secondly, by introducing a cloud-based solution for smart city services and thirdly, by doing a short foresight on future research challenges with relation to cloud computing adoption by smart cities.

The cloud computing model represents a fundamental change in the way that information technology hardware and software are created, developed, deployed, scaled, updated, maintained and paid[1]. It serves as an enormous step towards delivering global computing as a utility (like traditional utilities such as water, electricity and telephony)[2] by changing the traditional access model, where data and applications are fully contained in the same physical location (local computing), to a new one, where the users access their data and applications outside their own local computing environment through the internet.

The US Government's National Institute of Standards and Technology (NIST) defines cloud computing as "*a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction*"[3], while the IT research and advisory company Gartner uses a simplified definition and defines cloud computing "*as a style of computing in which scalable and elastic IT-enabled capabilities are delivered as a service using Internet technologies*"[4]. A common analogy to understand cloud computing is renting versus buying. Actually, someone rents IT capacity (computing power, disc space, applications, etc.) from a cloud service provider and consume them over the internet, instead of buying his own IT equipment. Moreover, he pays only for the resources he consumes.

Cloud computing promises economic benefits, speed, agility, flexibility, rapid elasticity and more innovation. The motivations of the organisations for the migration of their applications to the Cloud are closely related to the following key cloud computing characteristics:

- **On-demand self-service.** A consumer can unilaterally provision IT resources (e.g., storage, processing power, memory, bandwidth, etc.), as needed automatically without requiring human interaction with the cloud provider.
- **Broad network access.** IT resources are available over the Internet and accessed through heterogeneous devices (e.g., mobile phones, tablets, laptops, and workstations). There is a sense of location-independence because the customer generally is not aware of the exact location of the provided resources.
- **Rapid elasticity.** A cloud environment offers to the consumer the ability to rapidly scale up or down the IT infrastructure commensurate with demand. To the consumer, the capabilities available for provisioning usually appear to be limitless and can be reserved in any quantity at any time.
- **Measured service.** Cloud systems monitor, control and report the use of IT resources by leveraging a metering capability at some level of abstraction suitable for the type of service. This leads to a transparent relationship between the consumer and provider of the cloud service.

The above-mentioned characteristics create a highly efficient, scalable and elastic computing environment, which is available through a business model where consumers buy only the capacity and capabilities needed at any given time, instead of buying and deploying all the components of a computing centre.

Using this **"pay for what you consume"** approach, an organisation can significantly reduce the up-front costs by avoiding the procurement of hardware and software in advance, as well as the resultant infrastructure depreciation. Moreover, cloud adoption can decrease the operational costs, as the organization will maintain at a given time only the required resources, which could be scaled up and down through rapid elasticity. Also, other IT costs can be reduced by buying general purpose capabilities such as asset management, security, collaboration, etc. as a service, instead of maintaining a specialised in-house IT department. As organisations operate in an unstable economic environment, smart consumption-based procurement allows them to scale up to fulfil new demands and reduce spending, if necessary, to address changes in budgets and funding.

Besides IT cost reduction, the adoption of cloud computing increases significantly the effectiveness of an organisation in fulfilling its mission. The following benefits are clearly related to the ability of an organisation to deliver more and better results[5,6]: (i) Just-in-time infrastructure, (ii) more efficient resource utilisation, (iii) agility to respond to emerging needs, (iv) increased reliability and performance through the adoption of new technologies, best practices and security enhancements, (v) better information sharing and collaboration through the heterogeneous, location-dependent access, and (vi) evaluation and optimisation of business processes through enhanced real-time visibility and audit of applications and infrastructure.

Cloud computing can also serve as an enabler for innovation in the organisations that adopt it in a lot of ways: (i) reduces time to market by allowing the scale-up of resources in a cost-effective manner, (ii) gives constant access to commercial best practices and new capabilities, which can be incorporated to already existed services, instead of developing them in-house, (iii) enables the launching of new initiatives based on new applications that are available from the cloud provider, and (iv) connects to new and emerging technologies. Moreover, in government organisations, cloud computing can: (i) encourage entrepreneurial culture by reducing the risk of launching of new initiatives and by allowing the low-cost experimentation in new applications and services, and (ii) give them access to innovations developed by the private sector[7].

Organisations should also take into account, when they plan on their Cloud strategy, the deferent service categories and deployment models of cloud computing[3]. Table 1 summarises the options.

As organisations start migrating their applications to the Cloud, it is important to determine which applications fit better into this environment. The best candidates are the applications taking advantage of the cloud computing elasticity. For example, applications that are designed to spread their workload across multiple servers, applications that run occasionally but require significant computing resources when they run, and applications with unpredictable or cyclical usage patterns, will benefit from the Cloud's ability to automate the dynamicity of resources to match the current demand. For these applications, the rapid elasticity combined with the pay-by-usage characteristic of the Cloud can lead to significant financial savings[8].

2. Smart Cities and Cloud Computing

City governments and municipalities everywhere constitute for one thing complex public organisations that have more reasons to invest in cloud computing than any other public organisation. Despite their limited resources they have to provide a wide number of municipal services (ranging from sanitation, water, schools, health, transportation etc.) and serve the needs of their citizens in their daily life. At the same time, they face a variety of challenges including job creation, economic growth and environmental pollution. While it is widely accepted that increasing urbanisation strains the limited resources of cities and affects their resilience, it also highlights the need for sustainable urban development; especially in terms of much more efficient management of natural resources, such as energy and water, as well as better planning and collaborative decision making[9]. In this context, cloud computing can play a significant role, facilitating cities in meeting the above-mentioned tasks.

Over the past years, the term 'smart cities' has evolved to denote the cognitive processes combined with the deployment of ICTs, institutional settings for innovation and physical infrastructure, which taken altogether increased the problem solving capability of a city or a community[10]. The main features of a smart city include applications that connect, manage and optimise data from a complex set of devices, sensors, people and software, creating real-time, context-specific information intelligence and analytics, which aim to transform the urban environment and address its specific needs[11]. Managing such enormous amount of heterogeneous data requires, among others, high storage capacity and performance computing power[12]. For this, the latest developments in cloud computing and the Internet of Things (IoT) are widely deployed in smart cities[13].

More specifically, smart cities have to use a wide variety of ICT solutions to deal with urban problems and monitor their functions; they do not only require the use of new technologies and devices such as sensors, RFID (radio-frequency identification) devices, smartphones, smart household appliances, etc., to collect land use, transport, census, and environmental monitoring data which are generated every minute in the urban environment, but also the capacity to manage and process all this large scale data (Big data) in real time, in an interconnected and service/applications' specific way[14]. The emergence of cloud computing paradigm facilitates big data storage and big data integration, visualisation, processing and analysis in acceptable time frames. Fu, Jia and Hao[12] listed six reasons for the convergence of cloud and IoT in smart cities: (i) the immense storage capacities of cloud computing infrastructure, (ii) central processing capacity to perform complex computing, (iii) the ability for dynamic reconfiguration of resources, securing sufficient computational resources at any time, (iv) the

Table 1. Cloud computing service categories and deployment models

Service Categories	Deployment Models
• *Software-as-a-Service (SaaS):* The capability provided to the consumer is to use the provider's applications by running on a cloud infrastructure. • *Platform-as-a-Service (PaaS):* The capability provided to the consumer is to use the provider's development platform in order to create, test and host new applications. • *Infrastructure-as-a-Service (IaaS):* The capability provided to the consumer is for provisioning the process, storage, networks, and other fundamental computing resources in order to build a customised computing environment.	• *Private Cloud:* The cloud infrastructure is used exclusively for internal applications within an organisation. • *Community Cloud:* The cloud infrastructure is used exclusively by multiple organisations that have similar interests for collaboration. • *Public Cloud:* the general public access a provisioned cloud infrastructure for open use. • *Hybrid Cloud:* The cloud infrastructure is a composition of two or more distinct cloud models (private, community, or public). Data can be easily transferred between the different infrastructures.

ability to conduct system level comprehensive analysis with sample data, (v) high accessibility to various objects in IoT through user friendly applications and customised portals and (vi) high speed network and disaster recovery capabilities. Most significantly, cloud based big data mining and analytic tools can deal effectively with multi-disciplinary city data, characterised by environmental dynamism and spatiotemporal attributes, and formulate a variety of smart city application scenarios[9,15].

Apart from tackling persistent urban problems, cities of today also feel significant pressures to become sustainable and energy efficient. Cloud computing opens up new possibilities for sustainable solutions; it is not only the cloud's economies of scale which contribute to economic and environmental sustainability, it is also the fact that sustainability of future cities is mainly based on their ability to manage increasingly large and complex data (on the environment, waste, water usage etc.), a task that can be performed more effectively through the cloud. Smart buildings for example, which constitute the core of smart cities, need to rely on enterprise scalable cloud architecture so that they can benefit from functions such as stream analytics, machine learning, Hadoop, Spark, etc.[16]. Technologies in place today enable designers to integrate technical specification data about the materials, systems and equipment to yield greater efficiencies in terms of energy performance and better management throughout a buildings' lifetime. Just as any other aspect of a city, in order to manage buildings efficiently one has to metered its sub-systems such as lighting, electrical, mechanical, security etc. in an instrumented and unifying way; in fact, to do it on an aggregate level, for a group of buildings and across neighborhoods. This requires the ability to access, collect and analyse a large volume of mostly private data, which can be done by cloud computing in a more efficient and cost-effective way than traditionally dedicated computing solutions[17].

Real time processing of big data and the deployment of multiple applications is possible due to virtualisation, which is one of the main enabling technologies of cloud computing. Virtualisation software abstracts the physical infrastructures as virtual machines (VMs) and makes servers, workstations, storage and other systems independent of the hardware layer creating various dedicated resources according to the needs of the users. It increases infrastructure utilisation, enables more efficient use of the hardware and allows for true scalability and increased uptime[18].

Smart city solutions are applicable to all three service models of cloud computing (IaaS, PaaS, SaaS). Firstly, as already mentioned, cloud solution providers integrate IoT infrastructure (devices, networks) through virtualisation, offering computer resources as a utility (IaaS).

Secondly, cloud computing can shift domain specific tightly coupled systems (i.e., systems focusing on energy, transportation etc., orchestrated by domain specific service providers) to open domain-independent and scalable smart city services, provided through cloud based and domain-independent service-delivery platforms[19]. These constitute a type of Platform as a Service (PaaS) offering, which integrates and processes real time data from IoT and other data sources, and allows domain specific applications to employ both IoT and cloud resources on demand.

Thirdly, cloud computing can enable standardisation of smart city applications and turnkey solutions for software as a service (SaaS), providing on-demand self-services and decreasing significantly the associated development costs[13,20]. The provision of smart city services through flexible usage models and billing schemes, gives the opportunity to other cities with relatively limited budgets to make use of them. Standardisation of core city services, platforms and applications is extremely important as it accelerates technology diffusion and the uptake of proven smart city solutions, while at the same time enhances the emergence of collaborative innovation systems in these areas[20].

Much like open innovation, cloud-based smart city solutions require the collaboration among different actors of the urban ecosystem, meaning citizens, enterprises and the public sector. Besides, the existence of technologies being able to manage the cloud of things within cities does not automatically guarantee the development of smart city services[21]. According to Clohessy, Acton and Morgan[22], cloud computing smart city initiatives could harness the capabilities of open innovation paradigms such as living laboratories and crowdsourcing, taking full potential of the emerging collective intelligence. To this end, the use of open data is imperative for the development of innovative solutions and the opening up of new business opportunities.

Governments across the EU have initiated Government Cloud (G-Cloud) programs to deliver computing, storage and software capabilities to central and local governments using cloud computing. Government G-Clouds are considered as promising models for smart cities, which can create urban clouds that reduce IT costs, offering platforms for business applications and e-services[23]. Contrary to the abundance of G-cloud initiatives, Clohessy, Acton and Morgan[22] proposed the development of a single G-Cloud, with the collaboration of government, citizens, businesses, and researchers, which will implement a number of cloud technologies on a hosted platform to create and deliver an integrated pool of smart city services and solutions. Examples of smart city cloud based platforms include SCOPE, implemented in Boston, USA as well as SOFIA2, implemented in Coruna, Spain. Finally, in line with the above, we also see the emergence of a number of joint initiatives aiming to battle the fragmentation of efforts towards smart cities and cloud computing:

- EU's Memorandum of Understanding (MoU) on Smart Cities Open and Interoperable Urban Platforms, which aims to integrate data flows within and across city systems with the use of modern technologies (cloud services, analytics, social media) enabling cities to shift from fragmented applications and to create confidence on the demand side. The initiative is part of the European Innovation Partnership on Smart Cities and Communities[24].
- Cloud28+[25], a European-based community aimed at increasing the visibility and revenue of its members and accelerating adoption of cloud technologies through the creation of a cloud service catalogue, with a strong focus on compliance with the European rules on data privacy and security
- Eurocloud[26], an independent non-profit organisation acting as a pan-European hub, working towards the maintenance of a constant open dialogue and the sharing of knowledge between cloud computing customers and providers, start-ups and research centers.

3. Moving Smart Cities Applications to the Cloud — the STORM CLOUDS Experience

The STORM CLOUDS project[27] aims to accelerate the pace at which public authorities move to the cloud computing. The project provides a methodology for the Cloud migration process, mainly from the point of view of the end-users, as well as the essential IT tools that will support this process. By taking the STORM CLOUDS approach, public authorities can take full advantage of the cloud-computing model and provide to the citizens in a highly reliable and innovative services, despite resource constraints.

The main assets of the project are as follows:

- **STORM CLOUDS Platform (SCP).** The platform provides the Cloud environment, which can host Smart City applications.
- **Portfolio of Smart City Services.** The portfolio includes many cloud-based, open source applications, which are ready for public authorities use.
- **Roadmap for the migration of public services into the Cloud.** The roadmap consists of guidelines that help public authorities to address the technical and business challenges in the adoption of cloud computing.
- **Best practices for cloud-based public services deployment.** The best practices include software techniques and methodological approaches, which facilitate the adoption of cloud services in the public sector.
- **Business models for the scalability and sustainability of the project's results.** The business models cover the exploitation of the SCP and Smart City services, as well as the viability of the already 'cloudified' (turned into cloud-computing) services in the project's pilots.

The STORM CLOUDS Platform (SCP) has been implemented using open source technologies and solutions. This approach not only lowers the cost of the solution but also helps public authorities to avoid vendor lock-in, as it can be easily transferred in different Cloud providers. Another valuable feature of the platform is that it supports all Cloud deployment models (i.e., private, community, public and hybrid), as well as two of the Cloud service categories (Platform as a Service and Infrastructure as a Service). Figure 1 presents the logical architecture of the SCP. Table 2 presents the components of each layer.

The STORM CLOUDS platform offers great flexibility to the cities that will use it as the Cloud environment for their Smart City applications. Cities are free to select an external Cloud provider or build their own private Cloud or have a hybrid solution. In the latter case, the private Cloud will host high-risk applications — those with high privacy and security requirements (i.e., applications that contain customer data and other sensitive information) — while the public Cloud will host the rest of them. Moreover, cites are able to deploy its applications to the IaaS or to the PaaS Layer.

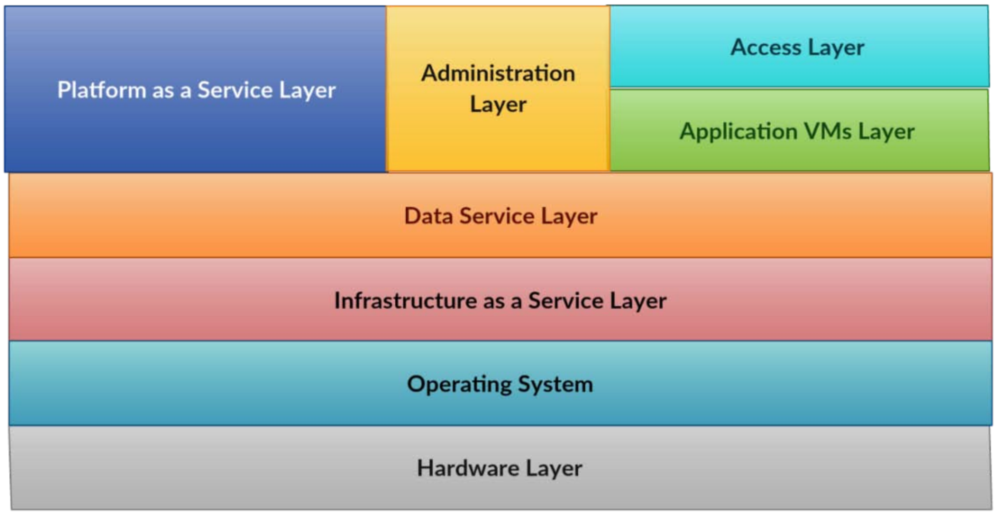

Figure 1. The logical architecture of STORM CLOUDS Platform.

Table 2. The components of STORM CLOUDS Platform

Component	Description
Hardware Layer	Physical resources (i.e., servers, storage, network, etc.) that host the platform.
Operating System	A Linux distribution that supports OpenStack (Debian 7.0, openSUSE, SUSE Linux Enterprise Server, Red Hat Enterprise Linux, CentOS, Fedora and Ubuntu).
IaaS Layer	It is implemented using OpenStack[28], the most popular and most adopted open source IaaS solution[29]. OpenStack can be seen as a cloud operating system that controls large pools of compute, storage, and networking resources (the hardware) and gives administrators a number of tools in order to deploy their applications.
Data Service Layer	Contains the database and the file servers, both deployed on VM clusters and provide high-availability and scalability. The currently supported databases are the MySQL and PostgreSQL.
Application VMs Layer	Contains the Virtual Machines that host the Smart City applications.
Access Layer	It is the front-end for the Smart City services. It receives the http(s) requests from users and redirects them to the suitable application's VM. It also implements the Load Balancer, which improves the overall performance of applications by distributing the workload in different VMs.
PaaS Layer	It is implemented using Cloud Foundry[30], a very popular open source platform for cloud applications.
Administration Layer	Provides to the platform's administrators and to the application owners, the tools that allow them to manage and monitor the components of the platform, as well as the Smart City applications. The tools include: • The Monitoring Module, which monitors the resources (CPU load, disk space occupation, network traffic, number of processes, etc.) used by the platform's services or by the applications. • The Database Administration Module, which administers the supported databases. • The Backup Module, which takes backups from databases and file-systems. • The Platform Administrator's Console, which allows the SCP administrator to have full control of the layers of the platform. Through the console, (s)he can manage the databases, the file-system, the IaaS layer, and the PaaS layers. Moreover, (s)he can deploy the Smart City applications to the IaaS layer automatically using a number of predefined scripts.

To decide which of the two options (IaaS or PaaS) they will follow, the public authorities should evaluate the pros and cons of each solution. On one hand, the IaaS offers excellent flexibility, as it does not require architectural changes to the applications, and full control of the resources used for the deployment. However, it increases the deployment complexity, as the applications' owners must take care of the installing and configuring of all components for its high availability and scalability. On the other hand, the PaaS "hides" the complexity of the underlying infrastructure and allows developers to deploy their web applications to the cloud without having to take care of the infrastructure. However, the applications may require significant changes[31] to comply with the PaaS principles and take full advantage of high availability and scalability features.

To address this problem, the SCP takes a hybrid approach and enhances the IaaS solution with two modules that provide the high-availability and scalability features in a way that is transparent to the applications' owners. By accompanying the IaaS layer with the Data Service and Access layers, the data and the HTTP traffic management are delegated to the platform while the application's business logic is still contained on the VM(s). The hybrid solution offers great flexibility as it does not require architectural changes to the applications but also keeps the deployment complexity low because the application owner "leverages" the high-availability and scalability features of the platform. The only drawback of this solution comparing with the SaaS is that the application's owners are not entirely independent from platform's administrators, as the later should configure the high-availability and scalability features per application.

Apart from the platform, public authorities have the access to a portfolio of Smart-Cities applications[32]. These applications have been successfully cloudified and deployed in a STORM CLOUDS pilot city. Moreover, they have been validated by citizens and public authorities in different European cities and, at the same time, are general enough to be transferred and deployed in other cities worldwide. The project's partners offer consultation and development services to the cities wishing to deploy the applications in their Cloud environment. The portfolio also contains all the necessary documents and guides, so that public authorities can evaluate the differences of the services when considering a cloud-based service deployment. Table 3 summarises the available services.

The Smart City applications are related to (i) City Governance, (ii) Innovation Economy and (iii) Quality of Life. Table 4 presents the applications per category.

The STORM CLOUDS methodologies and IT tools have been validated in a number of European cities. They constitute a valuable asset for the cities that want to leverage the cloud computing and be more efficient, agile, and innovative. The SCP is flexible enough to support the different needs and requirements of the cities, as it can support a variety of cloud deployment models and services' categories. Public authorities can use the already cloudified applications from Smart City services portfolio as a starting point to their journey to the Cloud. Moreover, by using the platform's tools, they can easily migrate from their existing applications to the Cloud environment.

Table 3. STORM CLOUDS portfolio of Smart City services

Service	Description
Virtual City Market	The application — on one hand — provides the possibility to every commercial enterprise located in the city to create its own virtual shop, and — on the other hand— enables customers to access a variety of retailers using a shared site. In its simplest form the service provides a list of the existing shops located in the city (and their location on a map) as well as their offers. The virtual city market enhances collaboration schemes among retailers offering the opportunity to create open malls and organise the shops per street or district.
CloudFunding	The application supports local communities to collect money for social and charitable purposes. It gives citizens and organisations the ability to co-finance projects for: (i) the improvement of the urban environment, (ii) social entrepreneurship and (iii) knowledge-intensive and technology-based youth entrepreneurship.
City Branding	The application promotes the identity of a city using interactive maps, 360^{o} panoramas, video and images. It enables Municipalities to focus on different target groups, which are associated with various aspects of city's identity by supporting the differentiation of the commons according to the target group in which the visitor belongs. Moreover, the application allows services provisioning based on the public space of the city and in particular around public commons, which are connected to local shops and services providers. In this way, local business communities can offer services tailored to the tourists' needs and expectations.
Improve My City	The application enables the citizens to report non-emergency local problems such as potholes, illegal trash dumping, faulty streetlights, broken tiles on sidewalks, and illegal advertising boards. The submitted issues are displayed on the city's map. Users may add photos and comments. Moreover, they can suggest solutions for improving the environment of their neighbourhood. Through this service, the Municipalities enable citizens and local actors to take action to improve their neighbourhood.
Vive	The application enables citizens to share information about leisure events in the city, map located and classified according to its cost (free, or low costs) and type (festival, movie, concert, etc.). The user could also see events close to her/his location.
Colabora	The application can be used to report issues in the street, but it has a very flexible data model that can be easily modified to represent many collaborative issues. A number of variations are available for: (i) urban issues, (ii) free or low-cost events and (iii) crime-spotting.
Have you Say	The application supports bottom-up decisions, by enabling Municipalities to ask the citizens' opinion about the future city plan, theme or issue. Both public authorities and citizens can upload photos and documents to support their opinion. Real-time statistics are also available for promotion of transparency in the participation process.

Table 4. Smart City services per category

City Governance	Innovation Economy	Quality of Life
• Have Your Say • Colabora • Improve My City	• Virtual City Market • CloudFunding • City Branding	• Live the City

4. Research Trends and Future Challenges

Based on the advances made so far, this section aims to highlight new scientific directions and future challenges with regards to smart cities and cloud computing. Although the trends that define the future of cloud computing can be numerous, ranging from technological aspects to new business models/opportunities, we identified four areas that are about to play a significant role with regards to cloud computing adoption from municipalities and city governments.

As Petrolo, Loscri and Mitton[33] mentioned, "in Smart City context, Cloud of Things (CoT) is expected to play a significant role in making a better use of distributed resources, achieving higher throughput and tackling large scale of computational problems, to enable the horizontal integration of various vertical IoT platforms and the Smart City vision". This means that over the next years, the focus will be on cloud platforms dedicated for IoT and on technologies for real time processing of big data and linked data. Advanced analytics over millions of data streams coming from highly distributed, heterogeneous, decentralised, real and virtual devices and data sources[9,15] which bring a new vision on the notion of cloud scalability. Here, issues of interoperability, privacy and security should be carefully considered.

The SCP could be expanded in order to enable the-rapid deployment of city wide networked sensors and actuators, as well as of IoT applications. Three new modules should be developed to support the core requirement of the IoT solutions:

- The Control Module that will handle the device interfacing and will enable the time-critical response. The module will consist of autonomous control applications and drivers which support a broad range of existing and new equipment and protocols.
- The Data Provisioning Module that will provide a unified sensor data acquisition in order to enable further processing steps. The module will store the acquired data in the SCP Data Service Layer. Data transformation techniques, such as data masking and data obfuscation, will be implemented in order to address privacy and security issues.
- The Big Data Analytics Module that will provide historic as well as real-time analytics. The historic analytics will identify data patterns of significance and will enable the optimisation of algorithms, services, and solution delivery while the real-time analytics will evaluate data as they come into the system in order to produce insights in near-real-time for immediate exploitation.

Apart from the development of the new modules, the platform's Data Service Layer should be enhanced with big data handling capabilities.

Although SaaS applications can offer higher flexibility and lower cost, integration between SaaS and on-premises legacy applications has been identified as a significant obstacle to adopt and deploy SaaS and other web-based applications. However, cloud integration does not only refer to cloud and on-premises integration, but also refers to integration among different clouds. Services convergence and multi cloud integration[34] is a promising paradigm, which creates new system design possibilities but also presents technological and management challenges, such as portability, compliance, elasticity and high availability[35]. These issues will be the focus of interest over the following years.

Despite the significant benefits of cloud computing in public administrations (cost savings related to scalability, increased efficiency, accelerated innovation etc.), there is still a lot of effort associated to the development and running of composite applications on the cloud. Based on the principles which are similar to the component-based software development (CBD) and service oriented architecture (SOA), cloudification of core application components and component portability can create repositories of the essential building blocks of smart city applications, reducing the cost of development and enhancing the emergence of new business models. The development of online libraries with re-usable software components providing different services for processing requests (e.g., database connection for the performance of database queries, user authentication, mail composing and sending, etc.) has had a significant background[36]. However, delivery of a service over different cloud providers requires specific considerations including issues of interoperability, reusability, open standards, etc.

Cloud computing encourages automation because the infrastructure is programmable. To ensure a high level of automation along with accuracy in the migration of the applications to the cloud, a set of tools and procedures have been developed and integrated into the SCP. The automatic deployment is implemented using OpenStack's orchestration engine to launch multiple composite cloud applications based on templates. The aim of orchestration is to create a human-and machine-accessible service for managing the entire lifecycle of infrastructure and applications within the SCP Cloud environment. Using these tools, the city of Miskolcin, Hungary, managed to move its applications to the Cloud within a period of two months.

Finally, we see the growth of cloud-based platforms and/or marketplaces being able to offer standardised core smart city services with on-demand infrastructure aiming to make smart city application deployment a simple process to follow. Marketplaces have emerged over the last few years as a way to provide a unified channel of distributing high quality cloud services, bringing together cloud service providers, data centre operators and technology partners[37]. The idea of having third party cloud-based applications integrated into one application suite has started gaining momentum as most municipalities do not have the resources, such as funds, expertise and available technology, which will enable them to move towards the vision of becoming a smart city. Cloud marketplaces and cloud-based application suites can help in speeding up the implementation process of smart city turn-key solutions in different domains of cities including transportation, sanitation, urban planning, policy making and so on. Research on this topic will have to focus also on issues such as Service Licence Agreements (SLAs), open standards etc.

Apart from the automated migration process, the SCP accelerates the uptake of cloud computing by public authorities in service provisioning, by offering a marketplace of commonly used smart city applications. Cities can provide cloud-based smart city services by activating their applications of choice and customise them depending on the specific characteristics of their cities. Using this approach, the cities, which participate in the STORM CLOUDS project, enriched their smart city portfolio by incorporating the applications from a catalogue of applications that has been cloudified in other pilot cities. The STORM CLOUDS marketplace will increase the number of generic smart city applications over the time, as the new cities that will migrate their applications to the latter platform will be offered the opportunity to add them to the catalogue while earning revenue each time another city uses them.

Conflict of Interest and Funding

No conflict of interest has been reported by the authors.

Acknowledgements

This paper is based on the experience gained from STORM CLOUDS, a project co-funded by the CIP-ICT-PSP program of the European Commission.

References

1. Marston S, Li Z, Bandyopadhyay S, *et al*. 2011, Cloud computing — the business perspective. *Decision Support Systems*, vol.51(1): 176–189.
2. Buyya R, Yeo C S, Venugopal S, *et al*. 2009, Cloud computing and emerging IT platforms: Vision, hype, and reality for delivering computing as the 5th utility, *Future Generation Computer Systems*, vol.25(6): 599–616.
3. U.S. Department of Commerce, National Institute of Standards and Technology, 2011, *The NIST definition of cloud computing*, viewed January 24, 2016, <http://nvlpubs.nist.gov/nistpubs/Legacy/SP/nistspecialpublication800-145.pdf>
4. Gartner, *IT Glossary: Cloud Computing*, viewed January 25, 2016, <http://www.gartner.com/it-glossary/cloud-computing>
5. Jinesh V, 2011, *Architecting for the Cloud: best practices*, Amazon Web Services, viewed January 24, 2016, <https://media.amazonwebservices.com/AWS_Cloud_Best_Practices.pdf>
6. *Best practices for federal agency adoption of commercial cloud solutions*, 2015, Professional Services Council, viewed January 25, 2016, <https://www.pscouncil.org/Downloads/documents/PSC-Cloud-WEB%20-%2012-10-15.pdf>
7. U.S. Chief Information Officer, 2011, *Federal cloud computing strategy*, White House.
8. Cloud Standards Customer Council, 2013, *Migrating applications to public cloud services: roadmap for success*, viewed January 25, 2016, <http://www.cloud-council.org/Migrating-Apps-to-the-Cloud-Final.pdf>
9. KhanZ, Anjum A, Soomro K, *et al*. 2015, Towards cloud based big data analytics for smart future cities. *Journal of Cloud Computing: Advances, Systems and Applications*, vol.4(2): 1–11. http://dx.doi.org/10.1186/s13677-015-0026-8.
10. Komninos N, 2013, Smart cities and the future internet: innovation ecosystems of embedded spatial intelligence,

Proceedings of International Conference for Entrepreneurship, Innovation and Regional Development, ICEIRD, 2013.

11. Mitchel S, Villa N, Stewart-Weeks M, *et al*. 2013, *The Internet of everything for cities: connecting people, process, data, and things to improve the 'livability' of cities and communities, point of view*, Cisco, viewed January 10, 2016, <http://www.cisco.com/c/dam/en_us/solutions/industries/docs/gov/everything-for-cities.pdf>
12. Fu Y, Jia S and Hao J, 2015, A scalable cloud for the Internet of Things in smart cities. *Journal of Computers*, vol.26(3): 63–75.
13. Schaffers H, Komninos N, Pallot M, *et al*. 2011, Smart cities and the future internet: towards cooperation frameworks for open innovation, in J Domingue, *et al*. (eds.) *The Future Internet — Future Internet Assembly 2011: Achievements and Technological Promises*, 431–446.
14. Mitton N, Papavassiliou S, Puliafito A, *et al*. 2012, Combining cloud and sensors in a smart city environment, *EURASIP Journal on Wireless Communications and Networking 2012*, 247.
15. Suciu G, Vulpe A, Halunga S, *et al*. 2013, Smart cities built on resilient cloud computing and secure Internet of Things, in *Control Systems and Computer Science (CSCS), 19^{th} International Conference, 29–31 May 2013*, 513–518.
16. Aditi Technologies, 2015, *Building "smart" cities on the Cloud*, viewed January 10, 2016, <https://blog.aditi.com/cloud/building-smart-cities-cloud/>
17. Microsoft, 2011, *The central role of cloud computing in making cities energy-smart*, Microsoft Corporation, viewed January 10, 2016, <https://www.microsoft.com/en-us/download/confirmation.aspx?id=5960>
18. Jarvis G, 2014, *Why virtualisation isn't enough in cloud computing*, CloudTech, viewed January 15, 2016, <http://www.cloudcomputing-news.net/news/2014/feb/12/why-virtualisation-isnt-enough-cloud-computing/>
19. Dustar S, Vögler M, Sehic S, *et al*. 2014, *The Internet of Things meets cloud computing in smart cities*, Bridges vol.41, OpEds & Commentaries, viewed January 15, 2016, <http://ostaustria.org/bridges-magazine/item/8280-the-internet-of-things-meets-cloud-computing-in-smart-cities>
20. Komninos N, 2014, *The Age of Intelligent Cities*, Routledge, London and New York.
21. Clohessy T and Acton T, 2013, Open innovation as a route to value in cloud computing, *26^{th} Bled eConference, eInnovations: Challenges and Impacts for Individuals, Organizations and Society, 9–13 June, 2013, Bled, Slovenia*.
22. Clohessy T, Acton T and Morgan L, 2014, Smart City as a Service (SCaaS): a future roadmap for e-government smart city cloud computing initiatives, *UCC '14 Proceedings of the 2014 IEEE/ACM 7^{th} International Conference on Utility and Cloud Computing, 836–841*.
23. Schaffers H, Komninos N and Pallot M, 2012, *FIREBALL White Paper: smart cities as innovation ecosystems sustained by the future internet*, viewed January 10, 2016, <http://www.urenio.org/wp-content/uploads/2012/04/2012-FIREBALL-White-Paper-Final.pdf>
24. *Market Place of the European Innovation Partnership on Smart Cities and Communities*, n.d., viewed January 14, 2016, <https://eu-smartcities.eu>
25. *Cloud28+: Europe's Cloud of Clouds*, n.d., viewed January 15, 2016, <http://www.cloud28plus.eu>
26. *EuroCloud*, n.d., viewed January 21, 2016, <https://www.eurocloud.org>
27. *STORM CLOUDS Project — main page*, viewed January 27, 2016, <http://stormclouds.eu>
28. *OpenStack — main page*, viewed January 27, 2016, <http://www.openstack.org>
29. *The top open source cloud projects of 2014*, viewed January 29, 2016, <https://www.linux.com/news/enterprise/cloud-computing/784573-the-top-open-source-cloud-projects-of-2014>
30. *Cloud Foundry — main page*, viewed January 29, 2016, <https://www.cloudfoundry.org>
31. *The twelve-factor app — a methodology for building software-as-a-service apps*, viewed January 29, 2016, <http://12factor.net>
32. *Storm Clouds Services Portfolio — main page*, viewed January 29, 2016, <http://stormclouds.urenio.org>
33. Petrolo R, Loscri V and Mitton N, 2014, Towards a smart city based on Cloud of Things, *WiMobCity '14, August 11, 2014, Philadelphia, PA, USA*.
34. Li Q, Wang Z, Li W, *et al*. 2013, Model-based services convergence and multi-clouds integration. *Computers in Industry*, vol.64(7): 813–832. http://dx.doi.org/10.1016/j.compind.2013.05.003.
35. Paraiso F, Merle P and Seinturier L, 2014, soCloud: a service-oriented component-based PaaS for managing portability, provisioning, elasticity and high availability across multiple clouds. *Computing*, vol.98(5): 539–565. http://dx.doi.org/10.1007/s00607-014-0421-x.
36. Heineman G T and Councill W T, 2001, *Component-based Software Engineering: Putting the Pieces Together*, Addison-Westley Publishing, Boston, USA.
37. Fugate R and Tang G, 2015, *Cloud market transformation, industry prediction update*, Cartesian, viewed January 29, 2016, <http://www.cartesian.com/cloud-market-transformation/>