Towards Refactoring in Cloud-Centric Internet of Things for Smart Cities

Research-in-Progress

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Abstract

Smart city is an urban development vision to integrate multiple Information and Communication Technology (ICT) and Internet of Things (IoT) solutions in a secure fashion to manage a city's assets. IoT devices are heterogeneous and collect large amount of data which need to be collected, processed, stored and shared among various devices, services and enterprise entities. Cloud technology has the potential to improve the performance, reliability and elasticity of software applications that drive the smart city vision. Due to the rapid increase in the number of devices, there is a critical need for the architecture of the cloud deployment to change constantly to adapt to the way these heterogeneous devices interact with the cloud services and on premise services are needed to migrate to cloud for the purpose of increasing performance and elasticity. Hence refactoring techniques could help tackling these issues as refactoring is a method of changing the internal design of the system while preserving the external behavior. In this paper we discuss refactoring and Cloud-centric IoT in the context of Smart city, problems related to the inter-connectivity of these paradigms.

Keywords: Refactoring, Smart cities, Internet of Things (IoT), cloud computing.

1. Introduction

According to Global Health Observatory data by World Health Organization (WHO), the urban population is expected to grow approximately 1.84% per year between 2015 and 2020. Therefore, cities need to be prepared to accommodate all the people without degrading the quality of life which means all the resources and services should be made accessible in a smarter way. ICT and IoT with the help of local governments and private enterprises helps realizing this vision (Zanella et al. 2014). Smart city is a vision to integrate various technologies which work together with a common aim to improve the quality of life. Smartness of a city can be divided among several sectors namely smart governance, smart mobility, smart utilities, smart buildings and smart environment. In this context, the IoT paradigm's popularity is growing due to constantly growing number of powerful devices like smartphones, tablets, laptops and other devices such as sensors which are interconnected through Internet. These 'interconnections' are exploited to create new range of services which help in various applications in everyday life. One example is live traffic monitoring which helps civilians to avoid congested roads, city officials to clear the traffic and so on.

Large amount of data generated in real-time by these heterogeneous devices makes in-house processing difficult and costly. The development in ICT technology suggests that services incorporated by IoT for sensing and actuating can be moved to a cloud. Petrolo et al. (2014) list and discuss some of the challenges that arise during the convergence of IoT and cloud computing infrastructures such as the following: (1) the interoperability amongst different ICT systems; (2) processing large amount of heterogeneous data provided by IoT devices deployed in smart systems; (3) fragmentation deriving from the multiple IoT architectures and associated middleware; (4) Resource orchestration. Concerning the challenges (2) and (4), cloud offers virtualization, high elasticity, storage capacity, performance and reliability, migration to cloud could enhance the data processing and data storage capabilities which are critical technological requirements for IoT.

The integration of IoT and cloud computing is referred as Cloud of Things (CoT) (Aazam et al. 2014), corresponding to Sensing and Actuation as a Service (SAaaS) and Things as a Service (TaaS) layers of the cloud. TaaS abstracts the underlying physical items according to things-like semantics (e.g. documents, cars, parts, products, etc.,). However, there is another important aspect of cloud, migration - a process of moving data, services and business elements to cloud from on premise servers. Cloud migration is adopted by many small-medium enterprises to increase performance, scalability, reliability and reduce cost. Cloud migration is needed for the smart city development as heterogeneous data generated by IoT devices cannot be processed or difficult to process and not cost effective by legacy systems which are in practice. Refactoring is essential when migrating on premise services to Multi-Cloud deployment (Jamshidi et al. 2015) as some applications are integrated and support core business process and services, many of which support utility needs, are non-core applications which meaning that these components are loosely coupled, which is one of the primary bad architecture smell that suggest refactoring. In this paper, we discuss IoT and Cloud in the context of Smart cities including issues and challenges in each domain and then section 5 aims to highlight the need for refactoring as a solution for the discussed issues.

2. Smart City

Smart city is an urban development vision that uses information and communication technologies to make the city services and monitoring more aware, interactive and efficient (Bélissent 2010). From a technological perspective, a “smart city” constitutes ubiquitous network of interconnected objects which extract (sense) information from the environment and interact with the physical world (actuation) while also providing services for information exchange, processing and applications over the internet (Jin et al. 2014). Smart city initiative contributes to the various sectors of a city such as transportation, utilities, healthcare, education, public safety, building management, constituent services and city management. ICT provides solutions which makes all these sectors smarter. In (Bélissent 2010) authors provide ICT infrastructure layers needed to realize smart city initiative as shown in Figure 1 which is divided into five layers such as

- *Smart city governance and management* which is composed of workflow, emergency command and control and city dashboard;
- *Smart applications* composed of public safety, Virtual city hall, Digital campus, eHealth, Building, automation and Mobile parking;

- *Smart city middleware* composed of Business intelligence, Unified communication, Web app, and integration software;
- *Smart city infrastructure* composed of network infrastructure, server and server virtualization and data capture infrastructure;
- *Smart cities advisory and managed services* which is the managerial layer of ICT infrastructure of a smart city.

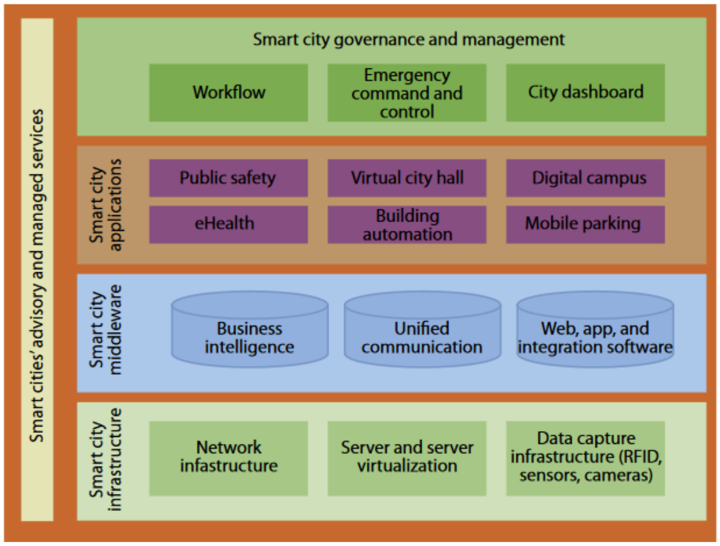

Figure 1: ICT layers in a smart city [source: (Bélissent 2010) **]**

A commonly employed strategy in urban process parameters is data collection, offline analysis and action; followed by system adjustments and repetition of the whole process (Jin et al. 2014). All these key fields of urban development incorporate the underlying ICT technology while constitutes ubiquitous network of interconnected devices. All these devices generate large amount of heterogeneous data and data collection exercises are often costly and difficult to replicate. Thus there is increased need for urban development agencies (government, public and private) to incorporate smart technologies to collect and analyze data in real-time. IoT technology could come in aid to address this issue by providing advanced data sensing, processing, actuation and analytics. Cloud offers great scalability for data analysis which is the core part of computing power for smart cities (Rong et al. 2014). CoT has the potential to enhance these capabilities by combining virtualization capabilities, scalability, vast data storage and processing power of cloud with sensing and actuation of IoT. Our work concentrates on the server and server virtualization of the smart city infrastructure layer (Figure 1). Server virtualization is responsible to address the scalability issues in the infrastructure level. In section 3 we discuss Cloud-centric IoT and various challenges faced in the context of smart cities.

3. Cloud-centric Internet of Things

The term "Internet of Things" was first coined by British visionary called Kevin Ashton back in 1999 while describing how internet-connected devices would change our lives (Wood 2015). IoT paradigm originated as a vision to interconnect various everyday objects through internet to achieve a common goal. Sensing, storage, analytics and interpretation are the essential qualities of IoT (Jin et al. 2014). The authors also discuss the importance of integrating cloud to balance the supply-demand as cloud technology integrates all facets of ubiquitous computing by providing scalable storage and computational resources to create an efficient IoT business model. IoT sensing devices sense (extract/generate) large amount of unprecedented heterogeneous data, this data has to be processed and made available to the actuation devices in real-time.

Cloud computing is of interest both for the industry and academy as it provides service provisions with low upfront investment, high performance, high availability, fault-tolerance capability (low down-time) and extreme scalability (Zhou et al. 2010). Services in cloud can be divided into three layers as shown in Figure 2:

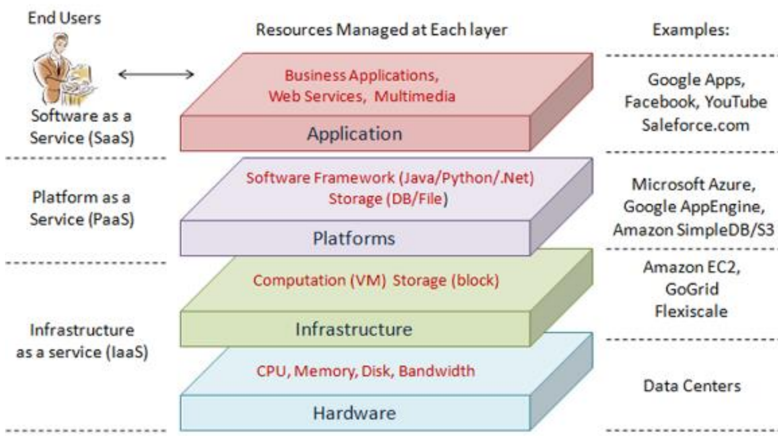

Figure 2: Cloud computing architecture [(Petrolo et al. 2014)**]**

- *Infrastructure as a Service (IaaS)* offers computing resources, both physical and virtual, for processing and storage.
- *Platform as a Service (PaaS)* offers development environment for software developers to write thier applications on a particular platform without worrying about the underlying hardware infrastructure.
- *Software as a Service (SaaS)* offers software applications that can be accessed and used by the end-users.

In addition to the aforementioned layers, additional ones are introduced such as Data as a Service, Everything as a Service, Network as a Service, Things as a Service and Sensing and Actuation as a Service (SAaaS) (Distefano et al. 2012) and so on. Cloud offers high computational power and scalability which are critical technical requirements for IoT serving as a backbone for smart city realization. CoT can make better use of distributed resources, integration of various IoT platforms and provide automatic sensor service relevant to the requirements. Another advantage of converging cloud and IoT is reducing the burden on “things” such as synchronization and integration of data harvested by various “things” will be performed transparently by cloud providers (Parwekar 2011). Lea and Blackstock (2014) provide a framework to develop and deploy smart city application by formalizing IoT framework as Smart city PaaS framework. Helfert (2016) discuss some of the challenges and solutions in Security, Service Negotiation as well as Power Consumption and Configuration in the Cloud. All these works prove that cloud computing contributes to the development and evolution of different aspects of the IoT domain.

4. Refactoring issues in cloud

Refactoring is the process of changing a software system in such a way that it does not alter the external behavior of the system yet improves its internal structure (Fowler 2002). Refactoring is a bottom-up process which helps clean-up inconsistent or insufficient design decisions which can be applied for design artifacts, models, documents, UML diagrams, processes and architectures (Stal 2007). The first step in the refactoring process is to identify the architecture smell – indication that usually corresponds to a deeper problem in the system, which identifies the need to apply refactoring and also indicates the actual refactoring to apply. Refactorings can be simple – move, add, rename, remove, pullup, substitute and so on and complex – combination of two or more simple refactorings. While these are general refactorings for any architecture, there are refactorings specific to cloud (Zimmermann 2015) – virtualize server, replace own cache with provider capability, move state to database, move workload to cloud etc.

Schmidt et al. (2012) describe an automatic architecture reconstruction and refactoring framework designed to reconstruct a conceptual architectural model for legacy systems and to migrate the physical architecture model of legacy systems towards a given conceptual architecture model. The authors implement Move Method, Move Constant and Exclude Parameter within their prototype and evaluated on a self-developed MVC style system. This work concentrates only on software migration from legacy systems and does not involve architecture smells that arise during the lifetime of the present day systems.

Strauch et al. (2013) discuss a step-by-step methodology that considers series of functional and non-functional requirements for the migration of database layer of the cloud and application refactoring required as the part of this process. This methodology is realized as a free cloud data migration tool that provides two fundamental functionalities: decision support in selecting an appropriate data store or service, and refactoring support during the actual migration of the data.

Based on the above discussion, we developed a table (Table 1: Architectural Refactoring (AR) offerings for CoT requirements) describing the CoT requirements for a smart city

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		CoT requirement			
		Legacy system Migration	Cloud-Specific Implementation	Automatic Adaptation	Scalability through virtualization (IaaS layer)
Architectural Refactoring offerings	Tool support	√	√	X	X
	Generic AR Catalogs	√	√	√	X
	Domain-specific catalogs	√	X	X	X

‘X’ – represents need for improvements

Table 1: Architectural Refactoring (AR) offerings for CoT requirements

Table 1 can be used to summarize the improvements needed in the field of Architectural Refactoring offerings to the cloud of things domain. We discuss how refactoring can be used to address Scalability through virtualization challenges in Section 5.

5. Refactoring as a potential solution

Refactoring should be applied every time a new component is added into the system as well as while the services are being migrated to cloud. Kwon and Tilevich (2014) developed a set of automated refactoring techniques which are aimed to improve performance, reliability and scalability of a software application while transitioning in-house services to cloud through migration. Use of such methodologies in the CoT virtualization domain could be beneficial to address scalability issues in the smart city domain.

Scalability in cloud deployments can be achieved through virtualizing underlying physical resources and offered as services. IoT sensor network utilizes these services in the terms of Virtual Machines (VMs) to achieve scalability and accommodate the workload requirements. Important prerequisite for scalability is that the system behavior should remain identical which is offered by refactoring. Cloud systems achieve scalability through virtualizing physical resources, yet refactoring is not considered in academia and industries in the virtualization area of cloud.

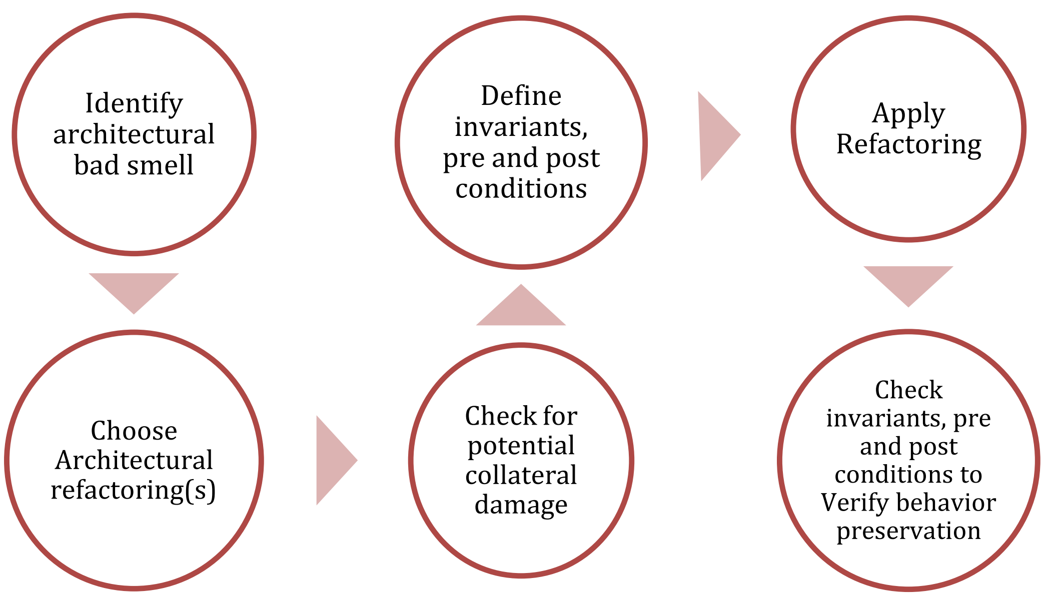

Figure 3:Refactoring process

Refactoring is applied following the series of steps (Figure 3): (1) Identify architectural bad smell, (2) Choose Architectural refactoring(s) to apply, (3) Check for potential collateral damage, (4) Define invariants, pre and post conditions, (5) Apply Refactoring, (6) Check invariants, pre and post conditions to Verify behavior preservation. Feller et al. (2012) developed a novel scalable and fault-tolerant VM management framework, utilizes a self-organizing hierarchical architecture and performs distributed VM management to achieve scalability. The authors claim scalability can be improved by *addition* of components - replication and additional load balancing layer, *replacing* components - NFS-based VM image storage will be replaced by a distributed file system; current in-memory repository implementation will be replaced by a distributed NoSQL database. This addition and *replace* of components indicate potential application of refactoring in the field of virtualization in cloud to improve scalability. However, this work fails to provide a compelling argument as to why and how scalability is improved. But, following the aforementioned refactoring steps could help in answering these questions. Hence refactoring can be treated as a potential solution to the scalability issues in virtualization area of cloud-centric IoT.

6. Conclusion and future work

Refactoring can be a potential solution to many of the discussed challenges as architectural refactoring is proven to improve the quality of a system. Though refactoring is applied in the area of cloud migration successfully according to the literature, there is huge potential for cloud refactoring in the architectural level in generic cloud deployments. Architectural decision making and architectural refactoring are significant responsibilities of software architects that are belittled in today's methods and tools. Though code refactoring is widely practiced and being implemented, architectural refactoring has been neglected. Since cloud architectures are massive and highly adaptable, there is immense need for architectural refactoring to be adopted in maintenance of cloud environments. This paper provides an extensive review of the smart city concept and IoT and cloud from the smart city perspective. We have also looked at the existing research and challenges in the respective fields that affect smart city realization. With an example, proved the potential of refactoring as a solution that address scalability issues in the virtualization area of cloud-centric IoT. The future work would be to develop a concept of following detailed refactoring techniques which includes methods to identify architecture smells in the cloud architecture, apply suitable refactoring and test applied refactoring to guarantee behavior preservation of the system.

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