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Lifecycle Based Modeling of Smart City Ecosystem

Ahmed Hefnawy^{1,3}, Abdelaziz Bouras^{2,3}, Chantal Cherifi¹

¹ DISP Lab, Lyon 2 University, Lyon, France

² DCSE, College of Engineering, Qatar University, Qatar

³ Ministry of Information and Communications Technology (ictQATAR), Qatar

Abstract - *Smart city services have an inevitable role in addressing the complexity of modern city operation. Smart transport, smart parking, smart energy, smart water and many others are examples of vertical smart city systems that are mainly concerned with its particular domain. Realizing the full promise of smart city will require interoperability among those systems and data fusion between heterogeneous components from different domains. In this regard, many standardization organizations have been working on modeling smart city and similar or related systems and concepts, such as Internet of Things (IoT) and Cyber Physical Systems (CPS), to ensure common technical grounding and architectural principles. Though, there is still a need to address the higher-level requirements of smart city as a complete ecosystem. To this end, this paper discusses different Smart City solutions and highlights lifecycle based modeling to better integrate people, processes, and systems; and assure information consistency, traceability, and long-term archiving.*

Keywords: Smart City; IoT; CPS; Data Fusion; Lifecycle Management.

1. Introduction

The world is witnessing continuous global tendency towards urbanization. The world's population residing in urban areas has increased from 30 percent in 1950 to 54 percent in 2014 and forecasted to reach up to 66 percent by 2050. In addition, by 2030, the world is expected to have 41 mega-cities with more than 10 million inhabitants [1]. On one hand, high concentration of population empowers cities and fuels economic growth. On the other hand, significant challenges of sustainability and complex city operation are likely to accompany advantages of urbanization. The increasing complexity of traffic congestions, waste management, human health concerns, environmental pollution, scarcity of resources and inefficient allocation makes ordinary service provisioning less effective compared with innovative smart city services [2].

The International Telecommunication Union (ITU) defines a smart sustainable city as *“an innovative city that uses information and communication technologies (ICTs) and other means to improve quality of life, efficiency of urban*

operation and services...” [3]. The British Standards Institution (BSI) was even more specific when described this innovative smart city as *“an effective integration of physical, digital and human systems in the built environment to deliver a sustainable, prosperous and inclusive future for its citizens”* [4]. The integration of physical and digital/ cyber systems, in co-engineered interacting networks, is widely known as “Cyber -Physical Systems” (CPS) [5]; or similarly, as “Internet of Things” (IoT) which is defined as “The global network connecting any smart object” [6]. The global connectivity feature of CPS and IoT fuels smart city with real-time data streams about certain characteristics of the real world [5]; and hence, smart city services empower city operators with real-time decision-making enabled by real-time data streams from heterogeneous objects. Smart transport, smart parking, smart energy, smart water are just few examples of smart city systems. Bearing in mind that the mentioned systems address sector-specific challenges; the resulting smart city applications appear as vertical silos, locked to specific domains, with less consideration to collaboration between those vertical silos.

In this regard, many standard organizations have been working on modeling smart city, IoT and CPS, to ensure common technical grounding and architectural principles. Though, there is still a need to address the higher-level requirements of smart city as a complete ecosystem. In fact, the smart city ecosystem is wider than only technical systems. The ecosystem equally includes human, whether users, policy makers, regulators, vendors, etc. The ecosystem has also business models and processes; and subject to applicable laws, policies and regulations. Finally yet importantly, the smart city ecosystem is more about the entire quality of life and living standards rather than isolated experiences in one or more sectors. Therefore, the objective of this paper is to consider high-level requirements of the smart city ecosystem in order to ensure horizontal flow of valuable information between multiple stakeholders, across different domains. S. Kubler, K. Främbling, et al. argue that this concept is closely linked to Lifecycle concepts, which is commonly understood as a strategic approach that incorporates the management of data, versions, variants and business processes associated with heterogeneous, uniquely identifiable and connected objects [7][8].

This paper proposes lifecycle based modeling of the entire smart city ecosystem to ensure systematic involvement and seamless flow of information between different stakeholders of the smart city ecosystem. The remaining of this paper is structured as follows: Section 2 describes the Smart City Framework (SCF), and other relevant concepts/views of CPS and IoT models. Section 3 explains the proposed high-level approach of lifecycle based modeling of smart city ecosystem. Section 4 discusses the proposed approach and the applicable lifecycle management systems. Section 5 sheds light on the conclusion of this paper and the proposed future work.

2. Smart cities reference models

Many standardization and research institutes are currently working on standardizing and modeling Cyber Physical Systems (CPS), Internet of Things (IoT) and Smart Cities. NIST is currently leading the work on CPS through the CPS Public Working Group (CPS PWG). From 2010 to 2013, the European Lighthouse Integrated Project “Internet of Things – Architecture” (IoT-A) developed an architectural reference model for the IoT, referred to as the IoT Architectural Reference Model (IoT-A-ARM). In 2014, the IEEE established P2413 working group with the scope to define an architectural framework for the Internet of Things (IoT). From 2013 to 2016, the CityPulse project has been working on Smart City Framework (SCF) to serve as a Reference Architecture Model [9]. The undergoing work in modeling of smart city, IoT and CPS, is very comprehensive and massive. For the purposes of this paper, this section focuses on SCF as the most currently available prominent reference model of smart city. This section also presents the IoT functional model, since SCF uses IoT sensors and actuators as one type of information sources and sinks respectively. Finally, this section presents the concepts of Lifecycle Management in the context of CPS.

2.1. Smart City Framework

The purpose of the Smart City Framework (SCF) is to set the main concepts, common language and the boundaries to be used by smart city stakeholders, partners and interested parties when engaged in technical discussions about smart city services [9]. There are three main groups of SCF stakeholders: City Stakeholders (IT service providers, City departments and City decision makers); Third Party Providers (e.g. App developers); and Citizens. The high-level view of SCF, illustrated in Figure 1, has different interfaces (I/F) towards the applications and towards the information sources/sinks. Information Sources include: Internet of Things (IoT) sensors deployed in a city environment; city information sources e.g. Open Data portals, city Geographical Information System (GIS) data etc.; and, user generated information through social media e.g. microblogs such as tweets that have been proven feasible for city related event extraction. Information Sinks include: IoT Actuators, City Datastores and social media channels through which cities could potentially push information to their citizens. The SCF consists of number of Functional Groups (FGs). The Large-Scale Data Analysis FG addresses issues related to integration of a large scale of heterogeneous sources producing real-time streams and their semantic enrichment. The Reasoning and Decision Support FG tackles issues related to the ability of the SCF to adapt to alterations based on real-time information streams. It is mainly responsible for monitoring the semantically enriched streams and adapting the collection of stream information from one side and providing an API towards the Smart City Applications from another side. The Large Scale Analysis and Reasoning and Decision Support functionalities are supported by prior knowledge in the form of the Knowledge Base FG and Reliability and Quality of Information control mechanisms by the Reliable Information Processing FG.

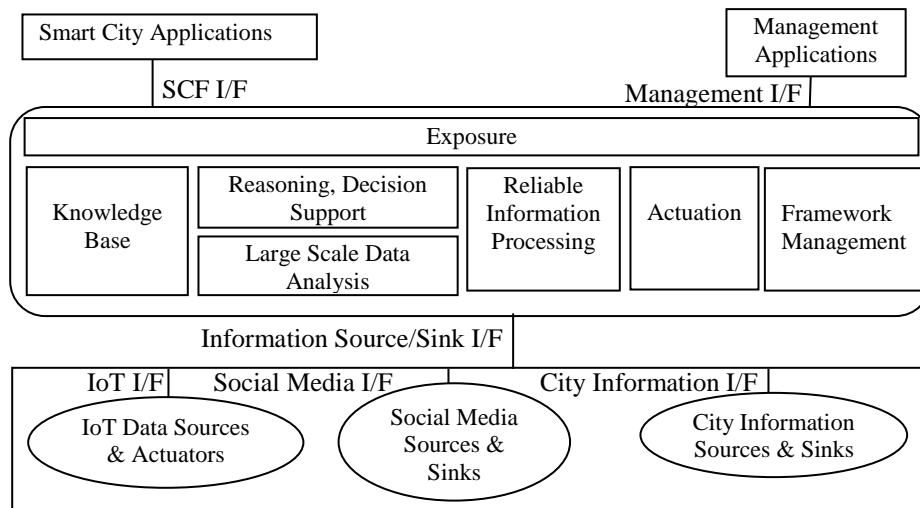


Figure 1: High-level view of Smart City Framework [9]

The Actuation FG covers any functionality that allows the SCF to push control commands or information to the IoT actuators, social media sinks and city information sinks. The Framework Management FG includes functionalities for the management of the SCF itself such as fault, configuration, security management etc. The Exposure FG covers the mediation of access with management and smart city applications.

2.2. Internet of Things approach

The IoT Functional Model, as proposed by the IoT-A project [6], illustrated in Figure 2, contains seven longitudinal Function Groups (FGs) (light blue) complemented by two transversal FGs (Management and Security, dark blue). The IoT Process Management FG relates to the conceptual integration of (business) process management systems with the IoT-A-ARM. The Service Organization FG is responsible for composing and orchestrating services of different levels of abstraction. It effectively links service requests from high level FGs such as the IoT Process Management FG, or even

external applications, to basic services that expose resources and enables the association of entities with these services by utilizing the Virtual Entity FG. The Virtual Entity and IoT Service FGs include functions that relate to interactions on the Virtual Entity and IoT Service abstraction levels, respectively. The Virtual Entity FG contains functions for interacting with the IoT System on the basis of Virtual Entities, as well as functionalities for discovering and looking up services that can provide information about Virtual Entities, or which allow the interaction with Virtual Entities. Furthermore, it contains all the functionality needed for managing associations, as well as dynamically finding new associations and monitoring their validity. The IoT Service FG contains IoT Services as well as functionalities for discovery, look-up, and name resolution of IoT Services. The Communication FG provides a simple interface for instantiating and for managing high-level information flow. The Management FG combines all functions that are needed to govern an IoT system. The Security FG is responsible for ensuring the security and privacy of IoT-A-compliant systems.

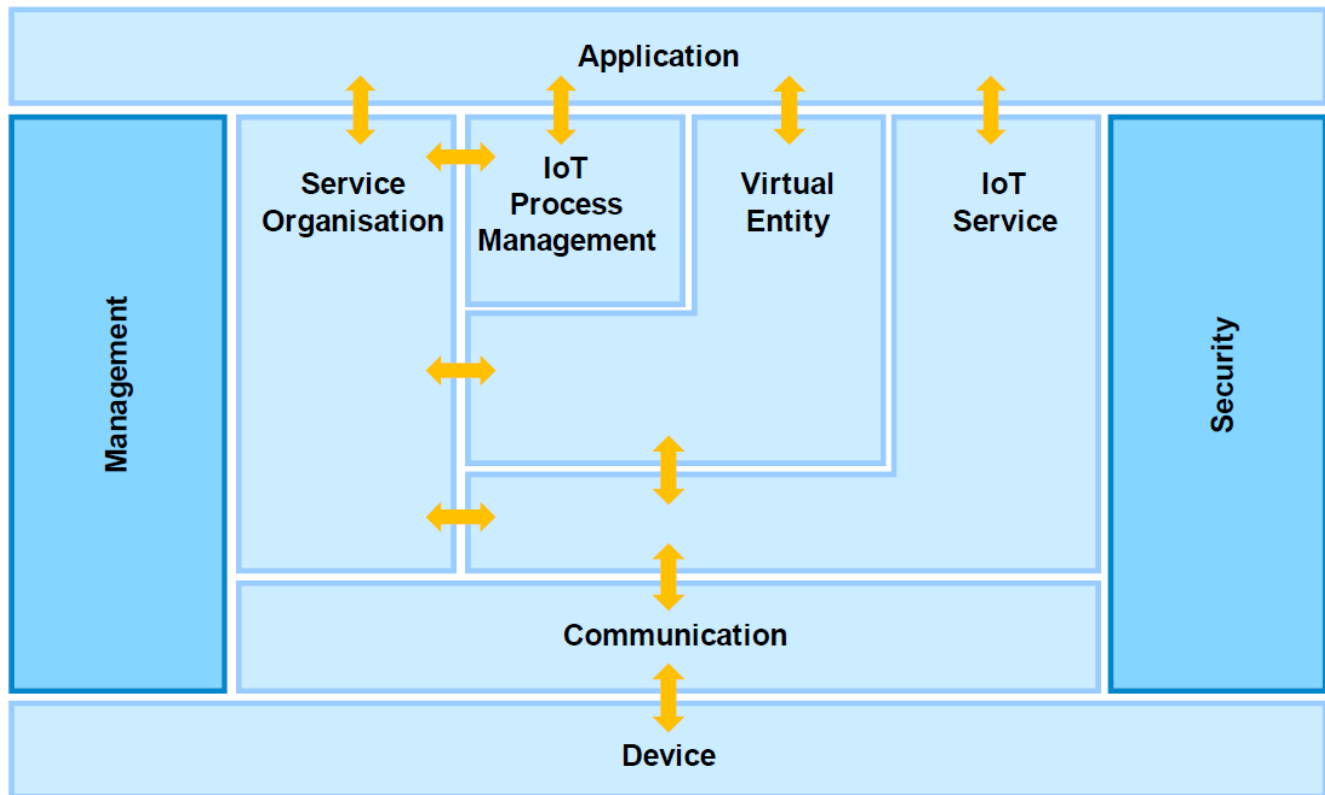


Figure 2 – IoT Functional Model [6]

2.3. Cyber Physical Systems and Lifecycle Management

The CPS Engineering Facet, as proposed by the CPS – Working Group [5], depicted in Figure 3, focuses on how CPS are made, using layers typical for engineered systems, such as Business, Lifecycle, Operation and Physical. The Business Layer represents societal, business and individual Requirements that needs business enterprises response. Existing and emerging government Regulation is another important part of the Business Layer. For large distributed CPS with many conflicting operational objectives, Incentives are important tools for coupling the business layer to all phases of CPS life cycle. The CPS lifecycle, similar to other engineered products, covers phases from engineering design through manufacture, to operation and to disposal of products. The Life Cycle Management Layer represents the four phases of CPS lifecycle. The Operations Layer extends to functionalities and services implemented by the networked interaction of cyber and physical components. The role of Cyber-Physical Abstraction Layers is to ensure that essential properties (such as stability or timing) are guaranteed by the introduced invariants. Among the many abstractions that are applied to CPS, functional abstractions are of special interest. The functional abstraction describes how a CPS is logically decomposed into components and a structure in which these components relate to and interact with each other to form the full system functions. Finally, the Physical Layer represents the physical part of CPS. All CPS incorporate physical systems and interactions implementing some forms of energy and material transfer processes. Physical systems include

plants, computation and communication platforms, devices and equipment [5].

Phases of the Lifecycle Management Layer

Design: Current engineering design flows are clustered into isolated, discipline-specific verticals, such as CAD, thermal, fluid, electrical, electronic control and others. Heterogeneity and cross-cutting design concerns motivate the need for establishing horizontal integration layers in CPS design flows. This need can be answered only with the development of new standards enabling model and tool integration across traditionally isolated design disciplines.

Manufacturing: CPS manufacturing incorporates both physical and cyber components as well as their integration. As product complexity is increasingly migrating toward software components, industries with dominantly physical product lines need to change. This transformation is frequently disruptive, requires the adoption of new manufacturing platforms, design methods, tools and tighter integration of product and manufacturing process design.

Operations: CPS operations cover the phase of the life cycle where benefits of new technologies are manifested in terms of better performance, increased autonomy, new services, dependability, evolvability and other characteristics.

Disposal: Cost of disposing physical components is integral part of the overall life-cycle management process.

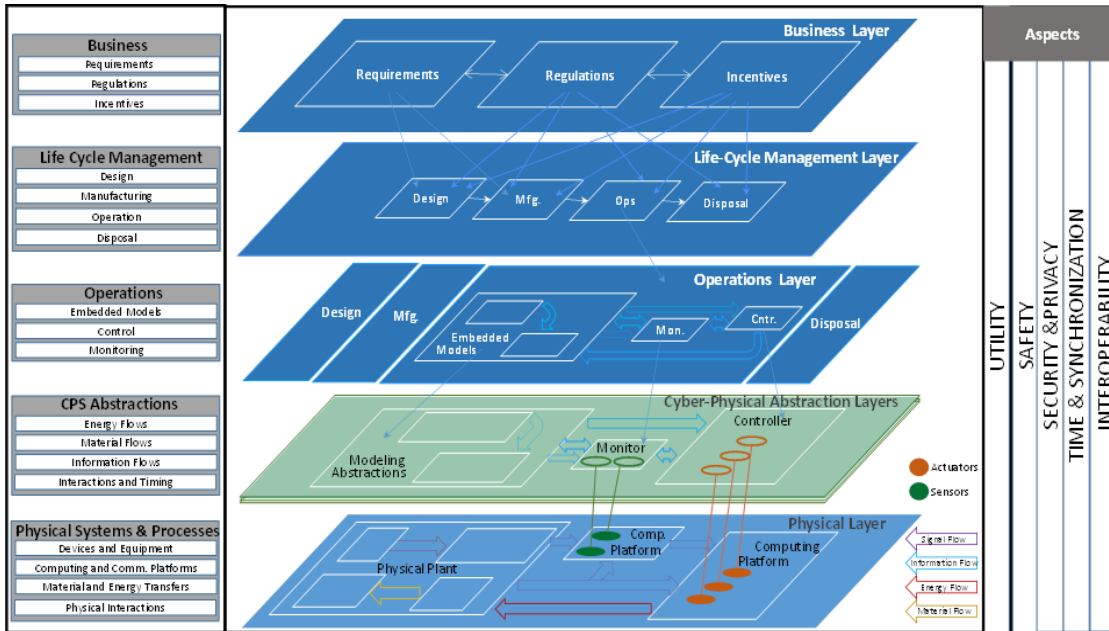


Figure 3 – CPS Engineering Facet [5]

3. Need for a global lifecycle approach

As explained earlier, the role of smart city solutions is becoming bigger in daily city operation. Yet, most of those solutions are vertically locked, where the data collection, processing, analysis and the resulting decisions and accumulated knowledge are normally locked within the boundaries of a particular domain: traffic, parking, energy, water, etc. Although, it is not expected that complete convergence will happen between those verticals; seamless flow of information can help horizontal integration to be realized. Such integration is important for efficiency purposes, taking into consideration that some parts of the value chain are not fiscally feasible or administratively possible to replicate. In this regard, many governments around the world have adopted open data policies to encourage/oblige government organizations to open up their data, and hence generate economic value and encourage entrepreneurship and innovation.

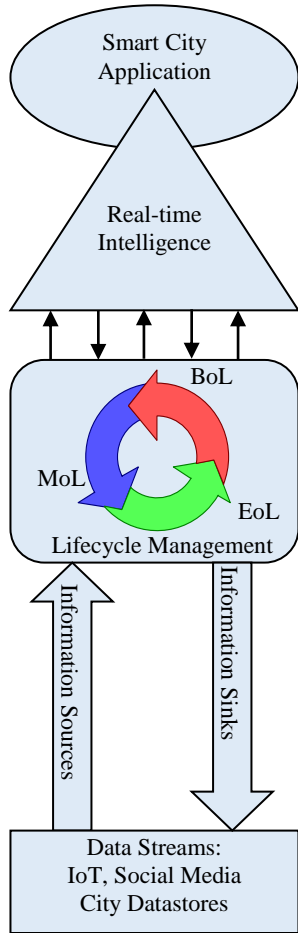


Figure 4: Smart City: High-Level Conceptual Model

On a very high-level, there is a need for a global approach that manages the collected data, processed information and accumulated knowledge according to a lifecycle point of view; and allows seamless flow between different domains, across all phases of lifecycle. To do so, the Smart City Framework (SCF) – discussed in section 2 – could be decomposed in order to decouple the information sources and sinks from real-time intelligence functions. In the meantime, a new Lifecycle Management function could be introduced to manage data, versions, variants and the business processes associated with heterogeneous, uniquely identified connected objects [7][8]. The Lifecycle Management shall support all phases of lifecycle; integrate people, processes, and technologies; and assure information consistency, traceability, and long-term archiving; while enabling intra/inter-collaboration within the same city and with other cities, if needed [10].

As presented in section 2, the CPS Architecture has proposed lifecycle management layer in its engineering facet. The proposed CPS lifecycle, similar to other engineered products, covers phases from engineering design through manufacture, to operation and to disposal of products. In such a case, Product Lifecycle Management (PLM) has been proven to trace and manage all the activities and flows of data and information during the product development process and also during the actions of maintenance and support [10]. Since the objective of this paper is to consider the entire smart city ecosystem, including stakeholders, systems, processes, etc., Quantum Lifecycle Management (QLM) can be more preferred than PLM. The Open Group has standardized Quantum Lifecycle Management (QLM) as an extension to and derivative of PLM [11]. However, PLM is mainly focused on information about product types and their versions, QLM may be applied to any “object” lifecycle including human, services, applications, etc. [11]. QLM messaging specifications consist of two standards: the QLM Messaging Interface (QLM-MI) that defines what types of interactions between objects are possible and the QLM Data Format (QLM-DF) that defines the structure of the information included in QLM messages [4]. QLM standards can serve the requirements of the smart city high-level conceptual model shown in Figure 3 from different perspectives. The QLM standards, as proposed by The Open Group, provide generic and standardized application-level interfaces [7] in order to create ad hoc and loosely coupled information flows between any kinds of products, devices, computers, users and information systems when and as needed [7]. In addition, QLM applies Closed-Loop Lifecycle Management (CL2M) that enables the information flow to include stakeholders and customers; and enables seamless transformation of information to knowledge [8]. QLM, through CL2M, enhances information security, interoperability, manageability; but most importantly for this research, information visibility and information sustainability to ensure data availability for any system, anywhere, and at any time, while being “consistent” (i.e., not outdated or wrong) [8].

4. Conclusion and Future Work

In this paper, it is proposed to use lifecycle concepts to model the smart city ecosystem. Current smart city, IoT and CPS models are more focused on the engineering system aspect; however, the proposed vision is to consider the entire smart city ecosystem: integrating people, processes, and technologies; and assure information consistency, traceability, and long-term archiving. Although, PLM has been proven very successful to trace and manage all the activities and flows of data and information during the product development process and also during the actions of maintenance and support; QLM adds new capabilities that make it more suitable for smart city modeling.

From another perspective, the proposed approach will develop and promote the smart city ecosystem. Taking into consideration that some parts of the value chain are not fiscally feasible or administratively possible to replicate, the proposed loose-coupling of information from data sources will generate economic value and encourage entrepreneurship and innovation.

However, the presented concepts have shown good level of applicability, it should be subject to more in depth practical test of implementation. The way forward can be using the QLM standards: Data Formats and Messaging Interface to model data exchange between multiple domains in the smart city ecosystem.

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