A Context-aware Strategy To Properly Use IoT-Cloud Services

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***Abstract*—Nowadays, we can talk about the Internet of Things (IoT) and Cloud computing union to indicate a new generation of distributed system. An IoT-Cloud system mainly consists of a set of smart objects which are interconnected through the Internet with a remote Cloud infrastructure, platform, or software. It allows to achieve new benefits in several contexts, such as smart cities and industrial businesses. In this paper we propose a context-aware strategy focused on the correct use of the IoT-Cloud services. In particular, a use case driven scenario and a three-step algorithm to define the strategy are presented and discussed.**

***Index Terms*—Big data, Cloud computing, context-aware systems, Internet of Things, multi criteria decision making, smart environments, smart cities, smart factories.**

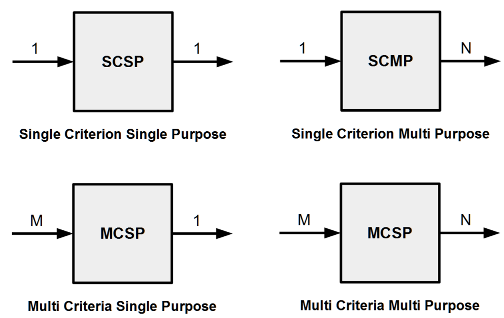

Fig. 1. The Four Criterion-Purpose Schemes.

I. Introduction

The proliferation of a wide variety of Internet-connected and low-cost devices is leading to the intensive worldwide use of the Internet of Things (IoT) [1] communication paradigm. IoT allows both public and private organizations to combine always-connected, non-invasive, smart objects (Things) [2] to improve everyday human activities in numerous contexts. Among the others, smart manufacturing and smart supply chain are example of the IoT to address efficiency in multiple industrial and business areas. Industrial production is evolving from the use of robots to the self-learning pervasive adoption of advanced smart sensors and objects to manage them. The companies intend to step up tracking capabilities and control of supply chains, with more computational power and more reliable and secure connections.

To this end, the combination of IoT and Cloud computing is pursuing new levels of efficiency in delivering services. The emerging business perspectives coming from IoT are pushing private, public, and hybrid *Cloud Service Providers (CSPs)* to integrate their systems with Internet-connected smart devices (including sensors and actuators) in order to provide Sensor and Actuator as a Service (SAaaS).

In any case, the IoT-Cloud union demands for a wide range of new "big data" capable technologies and services in order to manage both semi-structured and un-structured data. Various forecasts for IoT deployments have been offered by key industry sources, as reported in [3]. They estimate 65% in consumer, 21% for business across various industries and 14% in business/vertical specific by 2020. Moreover, Cisco [4] asserts the total amount of data created (and not necessarily stored) by any device will reach 600 ZB per year by 2020.

Due to the above trend, it is important to avoid a possible "dragging" effect without a careful evaluation of the real necessities for IoT-Cloud services. This means to properly characterize the *context*, and a *use-case driven* approach can help this evaluation for the correct use of the IoT-Cloud services. Concerning this "challenge", in this work we propose a **context-aware** strategy in order to choose the best IoT-Cloud Service Provider to manage heterogeneous smart objects. The strategy includes a preliminary characterization of the context mainly based on a *criteria-purposes* evaluation. The *criterion* is the metric that is used as a reason for making a judgment or decision. The *purpose* is the reason why the service is used.

Figure 1 shows the four possible combinations of services obtained from a context. They are based on the presence of one or more evaluation criteria and of one or more purposes (e.g., objectives, evaluation indexes, etc.). Examples of possible criteria-purposes combination in a decision-making scenario are obtained from the six-per-six criteria-purposes Table I. For example, the *C4, C5, C6* criteria can be used to evaluate the *P5, P6* purposes.

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TABLE I
EXAMPLE OF POSSIBLE CRITERIA-PURPOSES COMBINATION IN DECISION-MAKING SCENARIO

Criterion/Purpose	Energy consumption (C1)	Pollution (C2)	Cost (C3)	Troughput (C4)	Availability (C5)	Sizing (C6)
Energy-saving (P1)	✓	-	-	-	-	-
Low-carbon footprint (P2)	-	✓	-	-	-	-
Cost-saving (P3)	-	-	✓	-	-	-
Sustainability (P4)	✓	✓	-	-	-	-
Performance (P5)	-	-	-	✓	✓	✓
Maintainability (P6)	-	-	-	-	-	✓

SCSP: C1-P1; C1-P4; C2-P2; C2-P4; C3-P3; C4-P5; C5-P5; C6-P5; C6-P6.
SCMP: C1-{P1-P4}; C2-{P2-P4}; C6-{P5-P6}.
MCSP: {C1-C2}-P4; {C4-C5}-P5; {C4-C6}-P5; {C5-C6}-P5; {C4-C5-C6}-P5.
MCMP: {C1-C2}-{P1-P2}; {C1-C2}-{P1-P4}; {C1-C2}-{P2-P4}; {C1-C3}-{P1-P3}; {C1-C2}-{P3-P4}; {C1-C4}-{P1-P5}; {C1-C5}-{P1-P5}; {C1-C5}-{P4-P5}; {C1-C6}-{P1-P5}; {C1-C6}-{P4-P5}; {C1-C6}-{P1-P6}; {C1-C6}-{P4-P6}; ...

II. MOTIVATIONS

IoT can be considered as an enabler to manage "things" (i.e., sensors and actuators) for local execution, to allow data storage and computation through a Cloud-based "orchestration", and to make "intelligence" (i.e., knowledge) from data analysis. Several "top" IoT-Cloud service providers (e.g., Amazon) follow this approach. It is well known that *data* and *knowledge* are not the same thing: we can read a data in form of numeric value such as "21" or "475" from sensing device without knowing the real meaning, especially when monitoring heterogeneous parameters with unstructured data. The *context* links data and knowledge: in such a way users are sure that "21" is a temperature in Celsius degree and "475" is a power consumption in watt (e.g., in smart office, home application). In IT and Computer Science, we have to define a context as a *set of data* which is useful to make knowledge through specific tasks. This means to collect, process and manage data from heterogeneous sources, e.g., by means of *open hardware* and *open software* technologies (e.g., Arduino, OSHWA, OSS). Therefore, the main challenge is to extract "real" intelligence (i.e., knowledge) from data. A "big" amount of data represents a "big" opportunity to achieve high level of knowledge, but contemporarily it can represent a "big data problem". The risk is twofold at least: i) an IT system (i.e., infrastructure, software, platform) which is only able to manage structured data causing loss of possible "added value" by gathered semi-structured and unstructured data in a "big data context"; ii) an advanced IT system (e.g., Cloud-based) which results to be excessive for the real purpose, thus causing inefficiency, wastefulness in IT resources and cost (i.e., money). To this end, IT leaders (both in public and private scenario) should immediately characterize the context both in terms of purposes and criteria, and on the related amount of data to manage.

Figure 2 shows the high-level diagram of an IoT-Cloud service. It includes three computational layers, i.e. starting from the bottom, *sensing*, *gathering/processing*, *remote control and customization*, and two communication modalities, i.e., *proximity* and *remote*. Sensing includes several *Sets of Things (SoTs)*, each one involving a different number *(m,n,...)* of Things in different typologies *(a,...,z)* (e.g., smart lamps, locks, power strips, small motors, etc.). Data from SoTs characterize the *context*, that is the specific *Use Case (UC)*. Therefore we can talk about *Use Case driven* or *Context-aware* scenarios. Data gathered from sensing layer can be processed at the higher layer through the use of *Aggregation Node (AN)* devices, on the basis of the specific UC. Data can be accessed through the Internet both in proximity and by remote control (e.g., through the *WiFi 802.11 b/g/n*). The highest layer mainly includes the *IoT-Cloud framework* which provides services for authorized users.

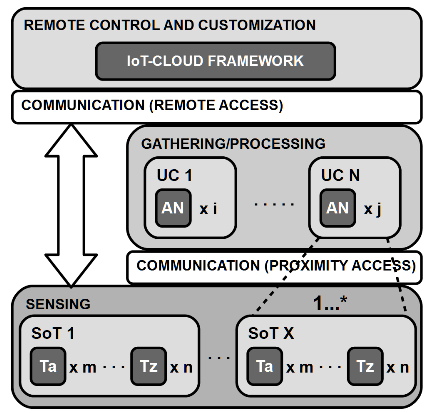

Fig. 2. High Level Diagram For IoT-Cloud Scenario.

III. RELATED WORK

State-of-the-art IoT applications are generally "black-box" and application-specific implementations. In [5], the authors propose a modular approach to context-aware applications, breaking down monolithic applications into an equivalent set of functional units, or context engines.

Cloud computing can cooperate with IoT by providing computing services in order to release the load of big data processing at user devices and some service providers. In [6] the authors propose a scheme of verifiable computing with *context awareness* and privacy preservation in IoT-Cloud computing. According to our approach, the work proves the importance of context-awareness by a specific use case.

Contextual information of data packet is desirable for performing in-network forwarding and processing: in [7] the authors present a context-aware IoT architecture to fill the gap between IoT and IP network leveraging Software Defined Networking (SDN) and Network Function Virtualization (NFV) through software-defined data plane. In [8] the authors discuss how self-learning can enable context-aware operation in communication systems to allow minimum energy/bit and energy/information.

One of the crucial research issues in IoT-based systems is how to manage the huge amount of data transmitted from sensing. The challenge of *how to* dispose big data generated from the devices is well-founded in [9]. Moreover, depending on the context in which data are gathered, only a fraction of the data would be needed for analysis [10].

In [11] the *SmartVent* context-aware IoT framework is proposed to monitor carbon dioxide emission, indoor air quality and ventilation. It is related to a specific context whereas the strategy we propose is easygoing to heterogeneous contexts.

A context-aware solution is proposed in [12]. A contextual requirement is represented in *condition* as composed of context name, operator and context value. This characterization is interesting for our strategy.

IV. Use Case Driven Scenario

Starting from the above-mentioned motivations and the state-of-the-art about IoT applications, in this Section we propose and discuss a context-aware and use case driven strategy. In particular, we propose a use case driven scenario and a three-step algorithm to define the strategy.

A. Use Case Driven Scenario: High Level Scheme And Description

Figure 3 shows a general scenario where an IoT-Cloud Framework serves several *Case Users (CUs)* on the basis of different contexts, i.e., the Use Cases (UCs). Each UC involves entities (i.e., CUs) with common purposes and people with different *roles*. Each CU is placed in a region with *rules* and *laws* to observe; it can be Public Administration, Enterprise, Industry, or simply makers which need to manage smart objects in smart environments (e.g., office, home, building, industrial plan, open space).

Therefore, a CU needs to monitor and/or control processes by *Sensing*, thus producing data to manage. To determine "what", "how many" data, and "where" is possible to setup the best IoT-Cloud services to manage them is a priority. To this end, it is possible to distinguish between *Internal Data (ID)* and *External Data (ED)*. ID can be managed by the CU through its own IT resources; ED are data which require *outsourcing* through an IoT-Cloud Framework which is able to dynamically manage data among CUs on large scale. The Framework should provide CUs with a *dashboard*. It should allow each of them to automatically detect if there are one or more CUs including the same UC, and to solve the above-mentioned priorities.

B. The Proposed Three-Step Strategy

Several procedural steps are necessary in order to determine "what", "how", and "where" is possible to setup the best IoT-Cloud services to manage data. To this end, we propose a three-step strategy which is synthesized by pseudo-code through the algorithm 1.

Algorithm 1 The Three-Step Strategy

```
step 1: Characterize the Context/UC
define PURPOSES P;
define CRITERIA C;
define DATA = f(typology, frequency, maintenance);
return UC = φ(P, C, DATA);
step 2: Determine how to manage DATA
if (DATA.typology=structured) then
    if (UC=single purpose) then
        case 1 : traditional IT system;
    else
        if (UC=multi purpose) then
            case 2 : Cloud system;
        end if
    end if
else
    if (DATA.typology=unstructured) then
        case 2 : Cloud system;
    end if
else
    if (DATA.typology=semi-structured) then
        case 3 : Hybrid system;
    end if
end if
step 3: Determine the Service Provider (SP)
SP = brokerage(UC, case x, SLAs);
```

1) The "What?" Question: The first step is to characterize the context on the basis of both purposes and criteria to evaluate them. This means to detect the specific UC and the related data to manage. The result is one among the introduced scheme (Figure 1). Data are in turn characterized at least by *typology, speed or frequency, running time or maintenance*. Typology means data are distinguished between *structured*, *semi-structured* or *un-structured* based on the initial presence of correlated (e.g., power consumptions inside home) or un-correlated (e.g., brightness from public lamps and traffic in a smart city context) data sources at sensing level.

2) The "How?" Question: Once the context is characterized, a second step consists in determining the *amount* of data to manage and the management system. At this step it is already possible to distinguish between three choices: *(i) traditional IT system*, *(ii) Cloud-based system*, *(iii) Hybrid system*. The (i) usually involves structured and no-big data by using *Structured Query Language (SQL)* databases (e.g., MySQL). The (ii) is necessary for a large amount of data from heterogeneous sources on large scale. It usually involves un-structured big data by using No-SQL databases (e.g., MongoDB). The (iii) hybrid system, whose scheme is shown in Figure 4, includes the previous two in presence of all the above-mentioned typology of data.

3) The "Where?" Question: Once the first two questions have been answered, a final step mainly consists in determin-

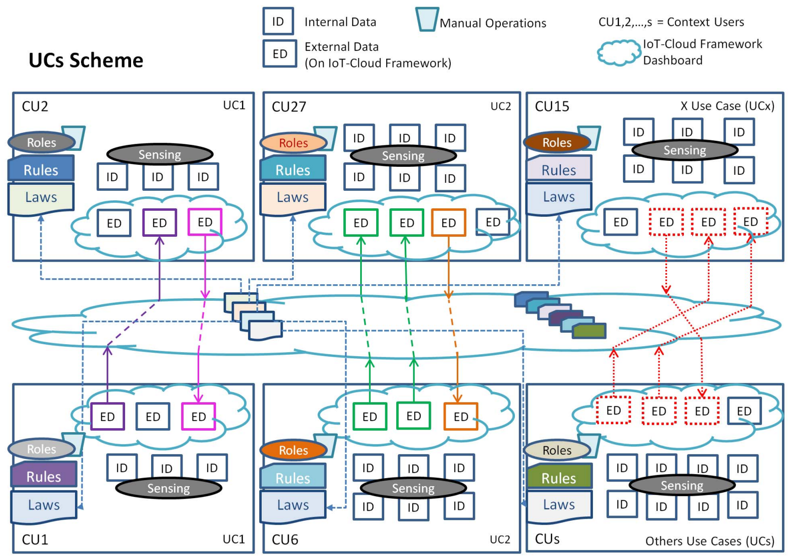

Fig. 3. Use Case Driven Data Management By IoT-Cloud Framework.

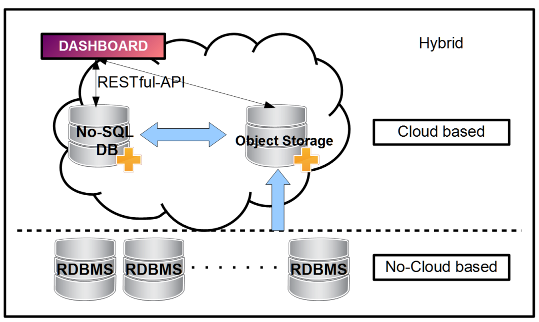

Fig. 4. General Hybrid System Scheme.

ing what data it is possible to internally manage and what need to be outsourced. This means to detect the best destination (i.e., the best Service Provider (SP)) in order to provide the IoT service for the applicant CU. At this step a *brokerage* function (a tool is proposed in next Section V) takes into account the *Service Level Agreements (SLAs)*. For example, the *ISO/IEC 25001–Systems and software Quality Requirements and Evaluation (SQuaRE)* [13] provides requirements and recommendations for an organization allowing to evaluate technology, tools, experiences, and management skills. Therefore, the IoT-CSP is responsible for managing technologies used for requirements specification and evaluation execution, specifying systems and software product quality requirements, supporting systems and software product quality evaluation, managing systems and software development organizations.

V. Evaluation

This Section presents and discusses two cases study in which the algorithm 1 is used. The first one is about the use of IoT-Cloud services by a small-size company. The second one concerns the request of a big-size company in the Oil & Gas industry. We simulate a brokerage environment with an additional computing layer (i.e., the broker) which acts as an intermediary between companies on one side and Service Providers (SPs) on the other.

Both the scenarios are simulated by using the *J2CBROKER* simulation tool [14] developed at the *University of Messina*. It is able to: *i)* dynamically manage JavaScript Object Notation (JSON) documents as inputs simulating both requests and offers by CSPs; *ii)* calculate the best choices (i.e., offers) on the basis of specific parameters through different multi-criteria JAVA engines; *iii)* provide the resulting best offers of its calculation. If compared with well-known simulators (e.g., CloudSim) it differs because its specificity in to simulate brokerage scenarios, with customized volume of messages between service providers and end-users/business customers.

A. *Case Study 1: Small-size Company Scenario*

The first case study concerns a small-size company which needs to outsource the management of its own IoT-Cloud services due to a rejuvenation process of its IT equipment. We assume services concern the collection of unstructured data typology.

1) Step 1: Table II reports the criteria we have chosen to address sustainability, maintanability and cost-saving purposes. It is an example of MCMP decision making application. Once both purposes and criteria have been identified, a brief dimensional analysis based on the chosen service criteria is executed. It is useful to understand the necessity in terms of data typology, frequency, maintenance, and if the case study 1 represents or not a *big data context*. To this end, by considering the Data Set in Table III and the Equation (1) we calculate the amount of data gathered from the sensing (i.e., a number S of 100 sensors) with C2 equals 500 messages-per-hour

TABLE II
CASE STUDY 1: CONSIDERED CRITERION-PURPOSE COMBINATION IN SMALL-SIZE COMPANY DECISION-MAKING SCENARIO.

Criterion/Purpose	DPPE* (C1)	Data flow (C2)	Cybersecurity (C3)	Time (C4)	Service Price (C5)
Sustainability (P1)	✓	-	-	-	-
Maintainability (P2)	-	✓	✓	✓	-
Cost-saving (P3)	-	-	-	-	✓

Unit of measurement: C1=evaluation index; C2=Messages-per-hour; C3=$Global\ Cybersecurity\ Index\ (GCI)$; C4=hours; C5=currency/Million-of-messages.
(*) DPPE stands for Datacenter Performance Per Energy.

Case Study 1: MCMP Data Set	
Criterion	**Range**
C1	0.5-5.0
C2	500
C3	[15]
C4	720 (hours)
C5	5-8 ($/million-of-messages)

TABLE III
THE CRITERION/RANGE DATA SET FOR THE FIRST MCMP SCENARIO.

(Equations (2). This means to determine the *storage capacity* to allocate an IoT service instance at a possible traditional IT or Cloud destination. Data are provided from *heterogeneous* and initially *uncorrelated* sources (e.g., employees position, environmental conditions), and each message payload P has been set to 512 byte in our simulation. This choice is reasonable if we consider that *512 byte* is the maximum payload size for each message for the *MQ Telemetry Transport (MQTT) protocol*, wich is used by several "top" CSPs (e.g., AWS) in their offered IoT services.

$$Data_{C2} = S * C2 * P * C4 \quad (1)$$

$$Data_{500} \simeq 17,17\ GB \quad (2)$$

The result is a 20 GB hard disk space per month is sufficient for the collection of data according to the simulated scenario (excluding the distribution of copies or duplication of instances, which are the prerogative of the Cloud service provider).

2) Step 2: Once the UC and DATA are characterized, the question is how to manage data. Step 2 answers this question. DATA typology is compared to the single/multi purpose question. To have unstructured data is a sufficient condition so that the step 2 results in a *Cloud system* (i.e., the case 2 in the algorithm).

3) Step 3: Through the J2CBROKER tool we simulated a *brokerage* based on a Multi Criteria Decision Making (MCDM) calculation among worldwide SPs that are geographically distributed among the CGI indexed countries (i.e., by considering the ranking of the country that hosts the evaluated service providers). We take into account the UC characterization, the necessity of a Cloud system and the C1-C3-C5 criteria as SLAs. The graph in Figure 5 highlights a comparison between the best SPs returned by the MCDM brokerage and the C1-based ranking among a set of 30 samples. The SPs are evaluated in terms of score from zero to one on the y-axis. The SP 2 (USA) score equals 0,96 but it is the best compromise

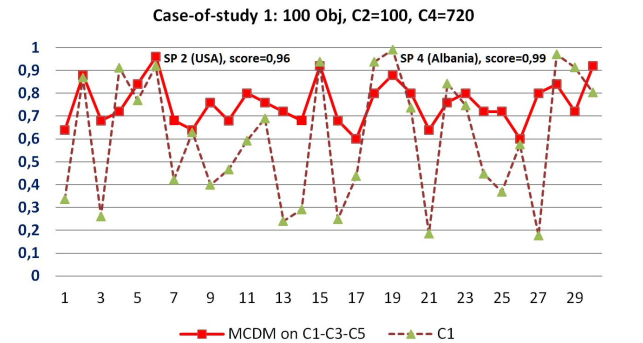

Fig. 5. Comparison between the results of brokerage simulation for the case study 1.

to satisfy all the selected criteria. The SP 4 (Albania) score equals 0,99 by considering only the C1 criterion (the DPPE evaluation index). This means it is the best choice only for the sustainability purpose (P1).

B. Case Study 2: Oil & Gas Industry Scenario

The second case study concerns a customized scenario for Oil & Gas (O&G) Industry. Typically it has hundreds, if not thousands, of unmonitored processes and systems exposed to unplanned failures or degraded operations. The risk can be to waste energy, to increase the probability of safety issues and others. In our simulation we consider the necessity to store both unstructured data from a number S of 15000 smart objects (e.g., for the traceability of specific modules for pipelines, human safety devices, etc.) and semi-structured in "on-demand" from a preexisting IT infrastructure (quantifiable in 10 GB-per-month).

1) Step 1: Table IV reports both criteria and purposes which allow to characterize the context. As the first one, this is an example of MCMP decision making application. Once both purposes and criteria have been identified, we calculate the amount of data gathered from the sensing with 1800 messages-per-hour. To this end, we consider the Data Set in Table III and the Equations (1), (3). Unstructured data are provided from *heterogeneous* and initially *uncorrelated* sources, and each message payload P has been set to 512 byte in our simulation.

$$Data_{1800} \simeq 220,20\ TB \quad (3)$$

If compared with the evaluation at the step 1 in the case study 1, the amount of data is much higher due to the use of a

TABLE IV

CASE STUDY 2: CONSIDERED CRITERION-PURPOSE COMBINATION IN INDUSTRIAL OIL & GAS DECISION-MAKING SCENARIO.

Criterion/Purpose	Availability (C1)	Data Flow (C2)	Cybersecurity (C3)	Time (C4)	Service Price (C5)
Cybersecurity (P1)	-	-	-	✓	-
Maintainability (P2)	✓	✓	✓	✓	-
Cost-saving (P3)	-	-	-	-	✓

Unit of measurement: C1=%; C2=Messages-per-hour; C3=$Global\ Cybersecurity\ Index\ (GCI)$; C4=hours; C5=$/TeraByte.

Case Study 2: MCMP Data Set	
Criterion	**Range**
C1	99.95-99.99
C2	1800
C3	[15]
C4	8760
C5	1k ÷ 55k

TABLE V

THE CRITERION/RANGE DATA SET FOR THE SECOND MCMP SCENARIO.

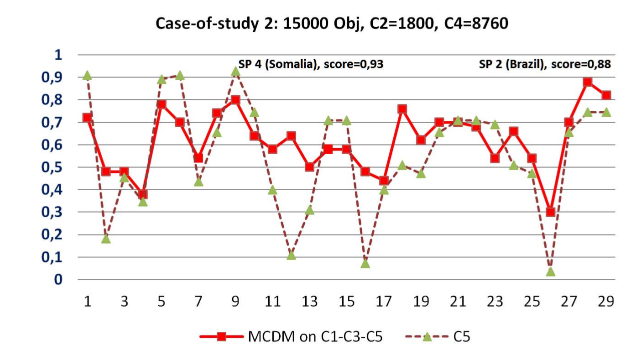

Fig. 6. Comparison between the results of brokerage simulation for the case study 2.

greater number of objects, to the higher frequency in terms of message-per-hour, to the longer time for the maintenance of services.

2) Step 2: DATA typology defined at step 1 is largely unstructured and in a negligible part semi-structured (initial assumption). However, the necessity to maintain the management of both data typologies results in a *Hybrid system* (i.e., the case 3 in the algorithm).

3) Step 3: Graph in Figure 6 highlights the best SPs returned by following the same procedure for the previous case study. The SP 2 (Brazil) score equals 0,88 but it is the best compromise to satisfy the C1-C3-C5 criteria. The SP 4 (Somalia) score equals 0,93 by considering only the C5 criterion (Service price). This means it is the best choice only for the cost-saving purpose (P3).

VI. CONCLUSION AND FUTURE WORK

The IoT-Cloud union bodes to achieve new benefits in several contexts, such as smart cities and businesses.

Starting from the above-mentioned motivations and the state-of-the-art about IoT applications, in this paper we proposed a context-aware strategy focused on the correct use of the IoT-Cloud services. In particular, a use case driven scenario and a three-step algorithm to define the strategy have been presented and discussed. They have been supported by two cases of study referred to the existence or not of a big data context.

In future works we plan to optimize the proposed strategy for the e-government context. It will be possible identify critical issues and metrics to evaluate services, for example to reduce costs and to save energy.

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