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A quality-aware context information selection based fuzzy logic in IoT environment

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***Abstract*— In the last decade, several works proposed their own approaches about the context management for the internet of things (IoT). An important issue in such systems is faced by context data distribution with a sufficient level of quality i.e. quality of context (QoC). In this paper, a fuzzy logic-based framework is proposed which handles QoC evaluating within distributed context manager and context-aware applications. This article presents also a solutions provided by the MDE (Model Driven Engineering) for modeling the captured context information from different context source.**

Keywords*— IoT; context *manager; MDE; fuzzy logic; QoC; context source; application.

I. INTRODUCTION

The IoT is the concept that aims to extend the regular Internet to the real-world physical objects. Consequently, a large number of things can be, at any time during their life cycle, either temporarily or permanently, connected to the global network infrastructure [1]. In Internet of things (IoT), there are numerous applications that are achieved by things collaboration. These applications use context information. There is a need to offer context information to the application layer in order to facilitate the development of new applications. This can be ensured by middleware. Such IoT middleware called context manager assumes to deal with a huge amount of heterogeneous data generated by devices, and transformed them to a high level of abstraction to provide users with valuable output. With the exponential increase in the number of context sources (ex: sensors) which offer the same type of context information that satisfies the requirements of the applications. It has become important to use QoC as an essential criterion to define the system requirements for selecting the context source, which ensures the quality required by application.

We have a previous study entitled "A Comparative Analysis of Context-Management Approaches for the Internet of Things" which published by The International Arab Journal of Information Technology (IAJIT). In this study, we evaluated the most popular context management approaches in the IoT using on a set of criteria: heterogeneity, mobility, the influence of the physical world, scalability, security, privacy, quality of context, autonomous deployment of entities, characterization multi scales, interoperability, context acquisition, context modeling, context reasoning, context distribution, design method, and tools of implementation proposed for this purpose [2]. An important issue like the criteria of the QoC is missing in the most of the studied approaches. They don't handle any solution for the QoC that leading an application for good decisions and relevant reactions. Based on our comparative study, we develop in this paper a fuzzy logic-based framework within a context manager to evaluating the QoC provided by each context sources and QoC required by application. The use of fuzzy-logic is motivated by its problem-solving methodology that can be implemented on any management system regardless of size, complexity of the problem [3]. This solution is an appropriate for being used in representation of non-functional attribute description. It looks like human reasoning for using approximate information and uncertain information provided by different sensors. It can effectively deal with the inherent vagueness and imprecision of QoC description both on the client and on the provider side: The fuzzy sets are suited to specify both the QoC requirements raised by an applications and an approximate estimates that a provider can make on the QoC guarantee which is able to provide. Fuzzy logic was used for selecting quality of context according to consumer's satisfaction-based preferences. It attempted to help the consumer in selecting the most matched quality of context through giving weights to available context sources. The contribution of this paper addresses three issues: First, we focus on non-functional parameters of QoC in information description to select context source according to the quality attributes of an application. Second, we propose a generic and extensible way to model the context information and the level of its quality which provided by different context source following a Model Driven Engineering (MDE) approach. Thirdly, we define a fuzzy-based framework for delivering the suitable QoC to user. Finally we apply our approach in an example extracted from the literature and we demonstrate its validity.

The rest of this paper is organized as follows: In Section II, we introduce briefly some related work. We formally describe our approach in Section III and its description is discussed with a case study example in section IV. Lastly, we conclude the paper in Section V.

II. RELATED WORK

Many research efforts have been undertaken to design QoC models. Some of them are cited in this section as follow:

Pierrick Marie (2013) [4] propose the QoCIM meta-model, aiming to define a generic meta-model for QoC [5]. QoCIM meta-model offers a generic, computable and expressive solution to handle and to exploit any QoC criterion within distributed context managers and context-aware applications [4]. Based on QoCIM, a graphical modeling tool for QoC criteria has been developed. It makes it possible to easily define new criteria or re-use existing criteria and to automatically generate the Java source code corresponding to each criterion.

The QoCIM framework for managing QoC metadata is composed of the following elements:

- A meta-model for the definition of QoC criteria;
- A graphical tool to use the meta-model;
- A library of functions for processing context information and their QoC meta-data;
- A tool for configuring the dissemination of information according to their QoC meta-data
- A support for the automated execution of processing functions;
- A tool for configuring the execution support for the functions [6].

This framework provide a graphical editor dedicated to graphically produce, at design time, new UML class diagrams of QoC criteria. With the editor, it is possible to edit the criteria by adding new definitions, new descriptions or new values of QoC. This graphical editor is not feasible; it should add the possibility to directly edit QoC guarantees, QoC requirements, and filters used for the dissemination [7].

The ANR INCOME project presented two framework MUDEBS and MUCONTEXT. MUDEBS is a framework offering content-based routing and is responsible for distributing context data but data models are manipulated in MUCONTEXT. This project has adopted an approach based on MDE (Model Driven Engineering) to create specific models for context contract definitions. This solution describes QoC meta-models by creating the MUCONTEXT Contract meta-model for context consumers and context producers [8]. Context Contract Meta-model defined the QoC concerns of decoupled context owners and context consumers. The meta-model of Context producer contract expresses the production of context data and QoC guarantees, whereas the meta-model of Context consumer contract expresses the consumption of context data, QoC requirements. The ANR INCOME project proposed an algorithm to create agreements among context producers and context consumers by evaluating and compare requirements against guarantees for the QoC [9].

Zied Abid (2012) integrated QoC management into the COSMOS (COntext entitieS coMpositiOn and Sharing) context management framework developed by the MARGE team of Télécom SudParis. He has designed the necessary components dedicated to QoC management. For this purpose, this work built a new node that allows managing the quality of context in the middleware of COSMOS and it has implemented the mechanisms allowing a good manipulation of the QoC. It also proposes a design process based on model-driven engineering in order to automatically generate the elements responsible of QoC management. The aim was to preserve compatibility with standard components (without QoC) and to propose a family of context nodes with QoC ready to be used in the construction of the context policy tree. Regarding the context management, this new framework is based on the concepts of context collector, QoC-aware context operator, QoC-aware context node and context policy. High-level context data are computed into context nodes. Context nodes are written with the COSMOS Domain Specific Language (COSMOS DSL) derived from the COSMOS meta-model [10, 11]. COSMOS is an oriented process and it is based on a set of software components. This type of imperative management does not favor the opening underlying the notions of context and situation [12].

Tao Gu [13] propose a formal context model based on ontology using OWL to address issues including semantic context representation, context reasoning and knowledge sharing, and quality of context. This context ontology allows the properties of entities to be associated with quality constraints that indicated the quality of context. This proposition for the quality of information comprise a quality Constraints that are used as quality indicators of OWL properties. Quality Constraints are associated with a number of quality parameters, which capture the dimensions of quality relevant to the attributes of entities and relationships between entities. Each parameter is described by one or more appropriate quality metrics, which defines how to measure or compute context quality with respect to the parameter. Such solutions are centralized and require significant computing and storage resources [12].

III. PROPOSED APPROACH

Our approach shows that a fuzzy-based framework and the methodology of MDE (Model-Driven Engineering) are feasible and necessary for supporting context modeling in IoT.

A. *Model-Driven Approach*

Is more suitable for the development of context-aware applications and context management system. Such an approach could facilitate developer's task at design time, by providing specialized modeling languages, meta-models and code generation tools [14]. MDE (Model Driven Engineering) provides a high level of abstraction and it makes available tools and grammars allowing the construction of context models which may be used to model context information and can be automatically transformed to particular target platforms [15]. The modeling language used in the majority of cases is the Unified Modeling Language (UML) [16].

B. *Functioning of our context manager*

Our approach is not focused on providing a complete software solution that addresses all the requirements needed in IoT paradigm. Instead, we focus on a single problem that is managing the quality of context information. We present and evaluate our approach: distributed context architecture with components for collection, processing and presentation of context information. Our context manager focuses on context processing assuming all the context data are produced by different context source. As a result, context architecture depicted in Fig.2 intended only to address that specific problem. Our architecture consists of three layers: context collection layer, context processing layer, context presentation layer. Most of the context management middleware solutions always have similar layers with similar principal. We propose a quick walkthrough of these layers:

1) Context collection: This layer appears in most the context management middleware solutions for IoT with different terminologies. This middleware are responsible for collecting the low-level context information from various available sources [17]. These context information and characteristics of context sources needs to be modeled in this layer. A model at this level will apply to a specific context source which provides a generic and expressive modeling solution for expressing the context provider. Our solution follows the MDE (Model Driven Engineering) to model context provider.

2) Context processing: The context processing layer is responsible for extraction of context information from low level context information collected at the lower layer [17]. It is the main layer of the proposed architecture, which is characterized by the fuzzy logic-based framework for QoC evaluation. A context processing executes different functions of fuzzy logic like fuzzification, Inference engine, defuzzification to deduce new context information like weight of each context source.

a) Application side: Initially, the end user gives request to context manager to find the list of context sources that are available to satisfy its need. User requirements are generally non-quantifiable. These requirements can be captured based on linguistic variables. We define the association of linguistic terms with fuzzy numbers in Table 1.

TABLE I. ASSOCIATION OF LINGUISTIC TERMS WITH FUZZY NUMBERS

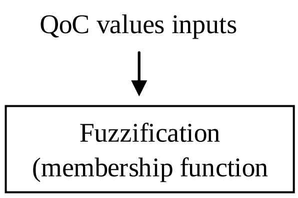
Linguistic variable	Fuzzy number
Low	0
Medium	0.5
High	1

The QoC description model of application request is defined as a triplet :(qa_i, wa_i ,ra_i). Where qa_i is the quality criterion in application requests, wa_i design the weight (importance) which requester assigns to the quality criterions, ra_i is requester's expectations of the quality parameter based on linguistic terms.

b) Context source side: we first assess context sources qualities (precision, completeness, etc) according to the properties of each sensor. Then we transform the values obtained from this assessment into fuzzy values using membership functions. The result of these membership functions allows the inference rules to derive the utility values of each context source.

The QoC description model of context source guarantee is defined as a triplet :(qp_i, wp_i ,rp_i). Where qp_i is the quality criterion in context source guarantee, wp_i design the weight (importance) which context source assigns to the quality criterions, rp_i is the level of quality of the context data that the producer is able to provide.

The total fuzzy system is described in Fig. 1



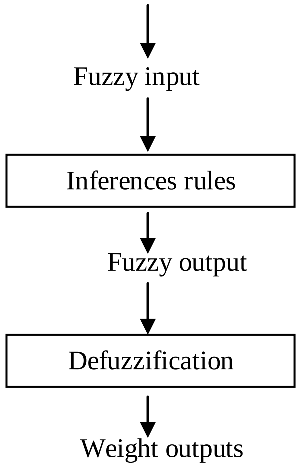


Fig.1 Fuzzy system diagram

3) Context presentation: is the point of convergence between the context information and associated QoC provided by context source and the QoC requirement by context consumer. This layer allows the selection of the context information which ensures the quality required by an application.

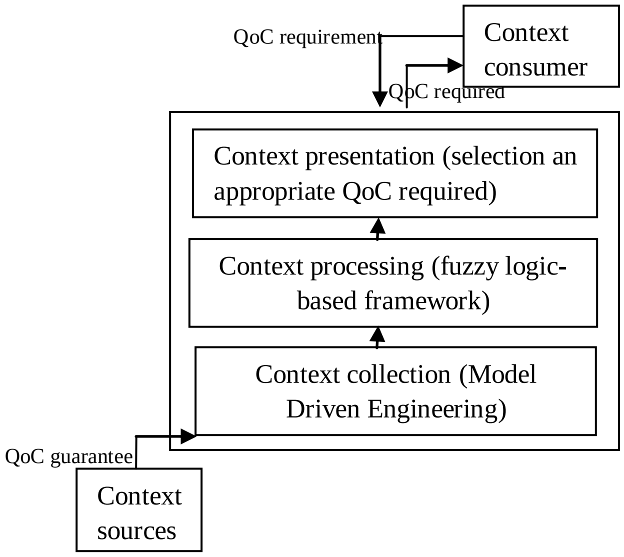


Fig.2 Architecture system

IV.USE CASE EXAMPLE

Our example aim at facilitating people and the supervision work in the nuclear industry, by providing context information to them. Field workers, participating in the nuclear activities, are equipped with applications running on mobile devices. The purpose is to offer solutions, based on QoC-aware applications to alert for a possible damage. Many parameters have been proposed and defined in the literature. Two QoC criteria are described in this example: the accuracy defined as "is the degree of the correctness of context or the capacity of sensor to measure a quantity close to actual value" and Timeliness defined as" is a quality measure that indicates the degree of the freshness of a context object at a given time" [18] which are the two QoC requirement of this application. To realize it, our context processing should be deployed over various servers, spread across heterogeneous networks or clouds and different sensors to collect as raw data measurements (e.g. Temperature).

In context collection: This phase provides a unified support to model any type of QoC criteria and context information of each context source. For this purpose, we are interested about using the MDE (Model Driven Engineering) which used in the majority of cases the Unified Modeling Language (UML). In the fig.3 we describe our model to illustrate how MDE can be used to model the QoC of context source.

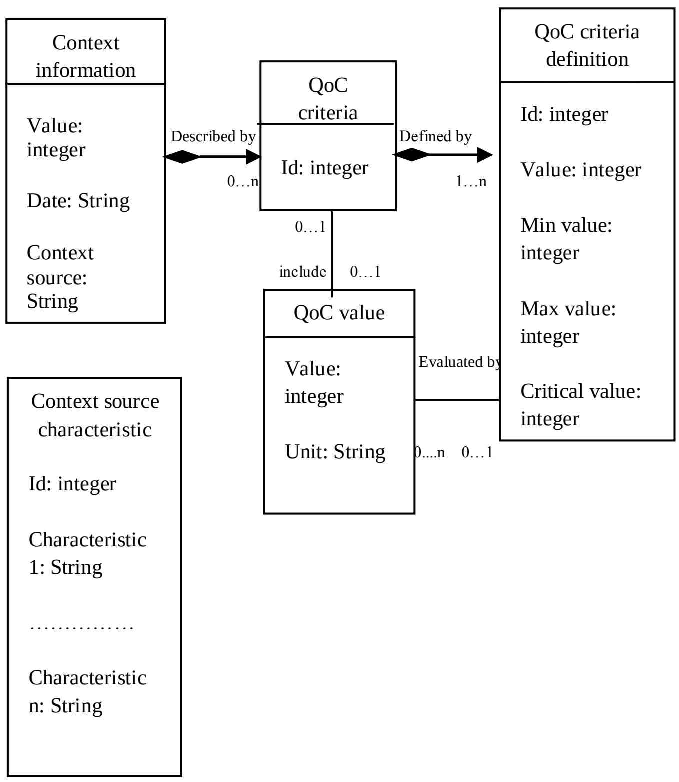


Fig.3 Context source Model

In context processing: this phase contains different steps that are needed to evaluate QoC metrics:

Step1: The user can specify his request based on the linguistic terms. Each of the request linguistic terms is defuzzified to derive one numerical value (described in table 1) that represents the value of each QoC parameters. An overall quality value of user requirement can be calculated taking into account the QoC parameters of a given weight for each parameter [19], as shown below:

$$QoC_{overall}=\frac{\sum_{i=1}^{n}(QoC_i * weight_i)}{\sum_{1}^{n} weight_i} \quad (1)$$

Where: n is the number of QoC parameters, QoC_i is the value of each QoC attribute; $weight_i$ is the weight of each QoC attribute.

In our example, for the QoC parameter (like accuracy and timeliness) the overall QoC value is:

$$QoC_{overall}=\frac{QoC_{accuracy} * weight_{accuracy} + QoC_{timeliness} * weight_{timeliness}}{weight_{accuracy} + weight_{timeliness}} \quad (2)$$

Step 2: Sensor characteristics are used to evaluate QoC parameters. These characteristics will include the information about the accuracy and timeliness which can have value in range [0-1], and their importance between 0 and 1.

Accuracy: first, we calculate the difference between the measured and true value of a quantity: E=M-T where E is the error in the measurement, M is the measured value, and T is the true value of measured quantity so accuracy is calculated as follows [18]:

$$Accuracy = 1-\frac{|E|}{T} \quad (3)$$

Timeliness: QoC parameter timeliness is calculated as follows [18]:

$$Timeliness=\begin{cases} 1-\frac{Age(I)}{Time\ period} & \text{if age(I)<time period} \\ 0 & \text{otherwise} \end{cases} \quad (4)$$

Where: Age (I) is calculated by taking the difference between the current time, and the measurement time of that context information, time period indicates the time interval between two measurements.

An overall quality value of context source guarantee can be calculated taking into account the QoC parameters of a given weight for each parameter, as shown below:

$$QoC_{overall}=\frac{QoC_{accuracy} * weight_{accuracy} + QoC_{timeliness} * weight_{timeliness}}{weight_{accuracy} + weight_{timeliness}} \quad (5)$$

Step 3: The QoC values of each parameter (obtained in Step 2) are fuzzified using three triangular membership functions [20]: $F_L(x)$, $F_M(x)$, and $F_H(x)$. They assess low, medium, and high membership values of quality parameters, respectively.

$$F_L(x) = \begin{cases} \frac{x-a}{b-a} & \text{if } a \le x \le b \\ \frac{c-x}{c-b} & \text{if } b < x \le c \\ 0 & \text{otherwise} \end{cases} \quad (6)$$

$$F_M(x) = \begin{cases} \frac{x-b}{c-b} & \text{if } b \le x \le c \\ \frac{d-x}{d-c} & \text{if } c < x \le d \\ 0 & \text{otherwise} \end{cases} \quad (7)$$

$$F_H(x) = \begin{cases} \frac{x-c}{d-c} & \text{if } c \le x \le d \\ \frac{e-x}{e-d} & \text{if } d < x \le e \\ 0 & \text{otherwise} \end{cases} \quad (8)$$

Where the constants: a, b, c, d and e are provided by an expert depending on the data.

Step 4: The fourth step is to take the fuzzified inputs and apply them to the fuzzy rules. Every rule of inference engine is written by the designer of fuzzy system based on knowledge that he has. For the QoC parameter (like accuracy and timeliness) the inference rules generated are:

IF accuracy low AND timeliness low THEN weight-sensor low

IF accuracy low AND timeliness medium THEN weight-sensor low

IF accuracy low AND timeliness high THEN weight-sensor low

IF accuracy medium AND timeliness low THEN weight-sensor low

IF accuracy medium AND timeliness medium THEN weight-sensor medium

IF accuracy medium AND timeliness high THEN weight-sensor medium

IF accuracy high AND timeliness low THEN weight-sensor medium

IF accuracy high AND timeliness medium THEN weight-sensor high

IF accuracy high AND timeliness high THEN weight-sensor high.

If we have several inference rules that generate several values of the same linguistic variable, we can choose an operator (AND, OR) to combine the values of the variable. For example, if we have three rules that generate the linguistic variable: weight-sensor is medium to 20%, 25% and 35%. If we use an operator OR (Maximum operator), the variable "weight-sensor is medium" will have a final value of 35%.

The reason for using the Fuzzy rule is it uses natural knowledge uniform representation since it uses IF THEN structure and it is easy to understand, read, add and modify the context source [21].

Step 5: The last step in the fuzzy inference process is defuzzification. We have a set of linguistic variables that characterize one and the same data. For example, we can have three linguistic variables: weight-sensor is low to 20%, weight-sensor is medium to 80%, and weight-sensor is high to 0%, which describes the weight-sensor. Defuzzing the weight-sensor data is to finding the best quantitative value as a function of the membership functions of the linguistic variables. We use the Center of Gravity (COG) [18] to determine the numerical value from the fuzzy value of weight-sensor (obtained in Step4) and it is used to get the weight of each context source as follows.

$$S= \frac{\int_{min}^{max} xF_S(x)d(x)}{\int_{min}^{max} F_S(x)\, d(x)} \qquad (9)$$

Where: S is the defuzzified output which indicates the numerical value of context source weight.

x is the output variable and $F_S(x)$ is the weight of the context source membership function for corresponding value of xi.

Step 6: in this step, we compared between the overall quality value of context source guarantee and overall quality value of user requirement and select an appropriate context source which satisfy user request. Once it has found a list of context source candidates, we choose the context source which has the best weight evaluated in step5.

V. CONCLUSION

In this paper, a fuzzy logic-based framework was proposed for context management for IoT. We use QoC parameters for context source selection. The selection process allows getting the best-fitting information which satisfy user request. Our model discusses sensor characteristics and context consumer requirements as QoC indicators that have been evaluated to passes QoC metrics along with context information to context consumer. Moreover, in this framework, we use a solution for designing context source and define their captured information following a Model Driven Engineering (MDE) approach. Our future work is to apply the proposed approach on a real dataset of context source guarantee and application requirements.

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