An adaptive Complex Event Processing-driven SIoT network formal metamodel*

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***Abstract*—Information, objects and people are the core innovation actors of human society progress. Their inner relations can be rebounded by the Internet, the Internet of Things (IoT) and social network, respectively. The integration of social networking concepts into the IoT solutions has led to the so called Social Internet of Things (SIoT) paradigm, according to the vision of a future world populated by intelligent objects that permeate the everyday life of human beings.**

In this context we propose an adaptive formal model for a SIoT network driven by a Semantic Complex Event Processing where "things"are capable of establishing social relationships with respect to their owners, according to the monitoring of sensors value, changed behavioral properties, state and/or context variables and user's preference.

I. Introduction

The huge amount of data flowing though Internet of Things (IoT) networks poses a big issue related to the discovery of objects that are able to provide data by executing specific services. The Smart Home is one of the focus area of the new IoT ecosystem era, both the centrality of the house in the life of every individual, with huge potential in terms of objects and distribution services, for both the bond with some of the leading sectors. Now, must be viewed as a dream where "things", particularly all home machines and more, are intelligible, locatable, addressable or controllable through the Internet.

When Social Networks meet the Internet of Things, the resulting paradigm is called *Social Internet of Things(SIoT)*. The idea to use social networking concepts in the IoT solutions to allow objects to autonomously establish social relationships is gaining popularity in the last years. [2]

The IoT-generated data come in big amounts, are variable in terms of structure, often do not arrive at real-time, and could undermine the purpose of the services offered. Traditional DBMSs, which need to store and index data before processing it, can hardly fulfill the concepts of timeliness and flow processing coming from such domains. Recently, new approach known as Complex Event Processing (CEP) emerged. CEP allows for efficient correlation, aggregation, and pattern matching of multiple distributed data streams on the fly [3].

In this paper we propose a Semantic CEP-driven SIoT network metamodel to communicate and interact with smart things that humans use in daily life taking into account relevant aspects adaptation: context, users habits and profiles, information detached from external sources and sensors.

The proposed approach allows modeling and reasoning on complex adaptive architecture according to changed behavioural properties or context variables [4].

*An extended version of this paper has been published at [1].

II. Proposed formal metamodel

In this section we describe our proposed formal metamodel that is made up of a inference level where incoming flows of information have to be processed to timely produce new flows as outputs (Sinks). The entities that create the information flows are called Information Sources. Sources and Sinks are interpreted in the sense of the CEP metamodel definition [3]. The events to be performed are derived from high-level properties, conditions about the state, context and sensor data.

Definition 1 (Event): Event is a thing happening in a definite time and environment, that some social entity take part in and showing some action features. An event e can be defined as the following tuple:

$$e ::= (A, A_c, T, E, A_{ss}, L_e),$$

where A is an agent, A_c is an action, T is a time, E is an environment, A_{ss} an assertions and L_e a language expression.

Intuitively, social entity (smart object or human agent) actions are the observations of sensor data, the publishing of a post and so on.

Definition 2 (SIoTN Ontology):

Social Internet of Things Network (SIoTN) Ontology formally specifies the shared and event classes. It can be defined as a quadruple formally.

$$SIoTNOntology =< Ec, Ei, R, e >$$

The elements in quadruples include the set of Entity classes, the set of Entity instances, the relationship $R =< Ec_i, Ei_j >$ (R includes parent-child, causal, follow and exclusion relations) and the correspondent event, respectively.

Thanks to the defined relationship between Entity instances it is possible to infer conditions between the entities, allowing the activation of a certain action.

Definition 3 (Context-aware SIoT Metamodel):
A Context-aware SIoTN Metamodel is a tuple

$$CaSIoTNM = < S_c, CEP, SIoTNOntology, S_k, Actions, C_x, U_m >,$$

where S_c and S_K are respectively the *sources* and *sinks*; CEP is an instantiation of CEP engine, C_x is the Context and U_m the user's model. The Contexts model every condition of the entity adaptation can have no effect on, e.g., instance, sensors data, geographical location, date/time, etc. Performed $Actions$ are based on continual query and pattern matching verifying ontological conditions.

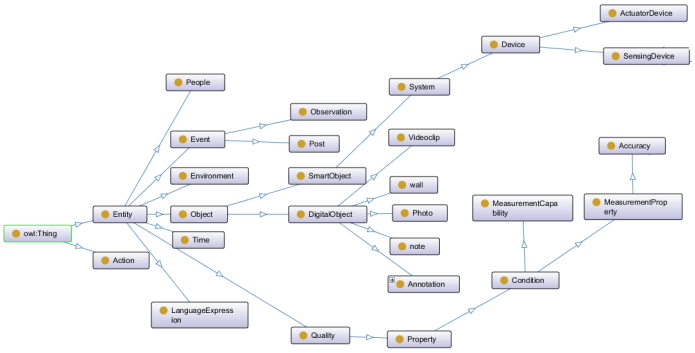

Figure 1. Part of the class hierarchy graph of the instantiated $SIoTNOntology$.

In most cases, a perfect match between the actual state and context, and the ones required in the condition is not to be expected. Given an ECA rule and a state-context $\tilde{S}$, *(i)* we need to evaluate if the state-context is "similar"enough to the one specified in the Condition (C part of ECA rule); *(ii)* we want to execute the Action (A part of ECA rule) whose condition C are more similar to $\tilde{S}$. When evaluating the condition C_i of an action A_i, most comparisons in C_i are evaluated as *fuzzy conditions* in Fuzzy Logic [5], an approach to computing based on "degree of truth "rather then the usual "true or false "boolean logic values [6].

The history of the user's behavior is stored in an ontological model through the values of the context and state variables describing the actions generally performed by the user and the related preferences. The CEP engine will choose among the pool of rules identified in the *ECA Rules Repository* the rule that verifies the constraint with the threshold t with respect to the triangular function of variable in the condition.

A. Prototype instantiation of the metamodel in Smart Home scenario

The proposed metamodel was instantiated in the domain of smart home. Table I summarizes, in this exemplifying version, how the elements in the tuple $CaSIoTNM$ are instantiated. Moreover, Table II presents an example of the instantiated (fuzzy) ECA rules.

Table I
INSTANTIATION OF THE ELEMENTS IN THE TUPLE $CaSIoTNM$.

Element	Instantiation
S_c	Entities that create the information flows: GPS device, smart home objects, human agent post and so on.
CEP	tool that operates according to a set of *processing rules*.
$SIoTNOntology$	A formal naming and definition of the types, properties, and interrelationships of the entities.
S_k	Human agents, devices and actuators.
$Actions$	Performed actions based on the combination of continuous query with context operators on received events, checking for correlations among these events.
C_x	Sensors in the external environments.
U_m	User habits (time lunch, sleep), the places already visited, how many times they were visited, preferences about smart devices states, type of medium supply, etc.

Table II
EXAMPLE OF (FUZZY) ECA RULE FOR SMART HOME SCENARIO.

EVENT: Recommend most used app at home CONDITION: $(gps = true)$ and $(gps.precision < x_1)$ and $(location = y_2)$ and $(time \sim 19:00)$ ACTION: Displays facebook, youtube, netflix, meteo apps
EVENT: Automatic ignition autonomous heating system CONDITION: $(gps = true)$ and $(season = winter)$ and $(radius > x_2)$ and $(radius < z_2 - x_2)$ and $(time = 18:50)$ ACTION: Turn ON rolling shutter actuator

In this instantiation we constructed an OWL 2 ontology to represent all the described knowledge related to the defined model by using *Protégé Version 5.1.0* editor (See Figure 1). CEP engine is responsible for observation, filtering, and pattern matching from data sources, based on the defined ECA rules, combining such notifications to sinks.

The proposed solution allows the communication between humans and smart devices to autonomously establish social relationships, providing automatic functionalities related to the home living, status change of smart home devices, include recommendations and so on.

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