Towards Theme Discovery Paradigm in the Internet of Things

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Abstract. In this paper, we present a novel concept for exploring the Internet of Things (IoT). We develop the concept of a Theme as a way of conveying the purpose of an IoT network, through the interactions of smart objects. This approach draws on the affinity between social networks and IoT and we consider the idea of 'friendship' between objects. Finally, we present the initial findings from a study involving a collection of instrumented objects and the identification of sequences and patterns in their data towards establishing the overarching theme of that test-bed network.

Keywords. Internet of Things. Social Networks. Human Computer Interaction. Theme Discovery.

1. Introduction

The Internet of Things (IoT) encompass a multitude of physical objects endowed with sensing, communication and processing capabilities (Kortuem et al., 2010). IoT involves "interconnected and instrumented ordinary physical objects…identifiable through network addresses so that they provide intelligent services" (Atzori et al., 2010; Ma, 2011; Perera et al., 2014). We extend this definition to include human users who, in some cases, become objects in the network by interacting and fulfilling roles within the system (Cervantes-Solis et al., 2015). As such, *Things* become smarter, aware of their environment and have the means of engaging in interactions with other *similar Things*, and their human users. This paradigm has been around for quite some time, in the form of pervasive and ubiquitous computing. As such, we consider that the IoT is not particularly a revolution in technology, but a revolution in the social organization of these smart, instrumented objects.

Current commercial and industrial deployments of IoT systems are interested in the collection of data towards the fulfilment of specific business models. Accordingly, it is not unusual for communication exchanges between things to occur at the data level, and for a digital representation of the object to be the main point of contact with the user, rather than the physical thing itself. Thus, things get digitised (Shin, 2014), presenting their features as the data they collect, i.e., barometric pressure, temperature, power consumption; or by describing their function, i.e., altimeter, thermometer, electricity meter, but not necessarily their intent (Yang & Newman, 2013). Thus, given this disassociation of the physical object and its purpose, information exchange might not be completely clear and straightforward to the user, leading to confusion and misunderstanding in the intended usage or expected outcome of the interactions (Yang & Newman, 2013). However, these devices are being increasingly adopted by humans into their everyday activities (Swan, 2012), for example wearable health trackers (Fitbit) or home automation (Nest Labs). As such, these things are interacted with in social scenarios, where the participants can be defined in terms of the roles they fulfil given their characteristics of sharing data and forming relationships: a user centric Social IoT as described by (Atzori et al., 2014; Guo et al., 2012). By considering these objects as entities with social traits, communication exchanges become more related to their role in a particular activity or their intention to achieve a particular goal, and less about their specific data. Thus, in contrast to industrial or consumer IoT systems, these exchanges actually become more of a conversation between the actors of this Social IoT. As a way to facilitate this understanding amongst its participants, it has been proposed that IoT networks have an overarching *Theme*, that can be communicated to nodes in the network (Cervantes-Solis et al., 2015).

1.1 Theme, topics and context

The concept of conversation in an IoT network, involves notions of *context*, *topics* and *theme*. We consider the ***context*** of the network as the clearly defined and mutual environment of things. For example, sensors collecting temperature readings in a single room are located in the same physical location. Moreover, when a particular collection of objects perform defined functions or attain their goal, we acknowledge that ***topics*** in the conversation are established. Extending the previous temperature control scenario, temperature sensors would communicate temperature readings to a control hub, whilst humidity sensors would exchange moisture levels. The control hub would then issue commands to adjust settings in the context. Two topics would be identified in this system: a "temperature control topic" and a "humidity control topic". Thus, the concept of ***theme*** in the IoT refers to the collection of *topics* that contribute to a conversation in a particular *context*, giving a high level definition of what the network does. Accordingly, the theme of our example network would be climate control in a certain environment. As such, instead of looking purely at data or sensor types, as current systems attain, we propose to investigate into the themes these networks convey.

1.2 Friendship relationships in the IoT

In any social network, friendship describes common interests and trust between parties (Nitti et al., 2014). For IoT, *conversations* should only occur with things that share a relationship, or are "friendly" to each other, and are relevant to the specific information exchange that they are having, in the same *context*. As described by (Atzori et al., 2014) things can build their own social network and generate new services from the collaboration with other friends in the network. Essentially, we exploit traits of friendship relations such as how friends might have mutual prior knowledge and shared of shared experience; friends might trust each other with personal or private information; friends might recommend other friends or might seek to protect their own friends.

Certainly, frameworks that build on these concepts would contribute to achieving the vision of an IoT that support and enhance human activities (Meder, 2014), by helping integration of the currently highly heterogeneous IoT ecosystems (Atzori et al., 2010). We propose that by establishing an information exchange where the theme of this conversation is fully agreed upon amongst objects, a more clear and meaningful interaction with these smart objects would occur.

1.3 Theme Discovery

The matter of how the IoT network conveys its theme is the main interest of this research. On the one hand, there is a requirement for the development of technical aspects for its implementation, such as specific protocols for device communication in the IoT (Fan & Chen, 2010) or the taxonomy and syntax of the data interchange (Zhu et al., 2005) . But there is also the aspect of investigating the tools and techniques with which the themes could be communicated by a network and understood by other networks and user. Akin to the development of the Semantic Web (Berners-Lee et al., 2001), these approaches look to establish semantics (Manat, 2014) and ontologies (Wang et al., 2012) that describe Human-IoT interactions in a conversation like exchange.

2. IoT Test-bed

As a way to look into the interactions of different sensors and the correlations they form with one another, a multi-occupant office in the School of Electronic, Electrical and Systems Engineering at the University of Birmingham was instrumented. Specifically, we consider the drinks that individuals in the office make, e.g., coffee, tea or water. As such, the devices involved in these activities were instrumented and given wireless communication capabilities (Table 1, and shown in figure 1). Thus, the context for the network was the specific office, the topics related to the use of different devices to make different drinks and the theme was "Drinks consumption".

Table 1. Objects in the IoT network with "Drinks consumption" theme.

Device	**Action registered**
Office door	Opened and closed
Fridge door	Opened and closed
Coffee machine	Handle lifted
Water dispenser	Hot and cold water buttons pressed
Cup coaster	Cup placed
Window	Window opened or closed

From the perspective of the smart objects, a common interaction with the system would be described as:

"a person walks into the office [door activity is registered], places cup in coffee machine, lifts the coffee machine handle [coffee machine activity is registered], places a coffee capsule in the machine, presses down the coffee machine handle [coffee machine activity is registered], removes cup from coffee machine, walks to water dispenser, pours hot water in coffee cup [hot water button activity is registered], opens door, leaves the office]".

Figure 1. Instrumented devices for IoT network with "Drinks consumption" theme.

The study required all the users to document any "Drinks consumption" related activity into a log, making note of the date and time, their name and of course the activity. This allowed for the creation of a timeline of activities for each user in any given day (Table 2). Simultaneously, the instrumented objects automatically recorded the time and date of their activation.

Hence, the context in which the devices operated was "the office", whilst the topics communicated were the actions logged by the network coming from each of the instrumented devices.

3. Results

The aim of the study was to identify and reconstruct the activities the users recorded in the log. Table 2 shows User 3 registered in the log that he made a Coffee with hot water at 12:09 pm.

Table 2. Activities reported by Users.

User	Date	Time	Activity
User 3	21/09/2015	12:09:00	coffee + hot water
User 2	21/09/2015	12:29:00	hot water
User 4	21/09/2015	13:57:00	water (hot + cold)
User 2	21/09/2015	14:13:00	changed water dispenser bottle
User 2	21/09/2015	14:13:00	hot water

Table 3 shows the processed sensor data. A sequence of sensor activations is shown for this user, starting at *12:05:54 PM* with the *Door node* registering his entrance to the office, and ending at *12:08:42 PM* when "hot water" was poured into his coffee mug as verified by the corresponding sensor (it is until this moment that the user makes a record of the activity in the log). At *12:28:27 PM* the *Door node* became active again, and although the identified user is User 2, it is shown that said person registered in the board that he was pouring hot water into his mug (Table 2). Therefore, it is inferred that User 3 left the room 20 minutes after he prepared his drink.

Table 3. Data collected from instrumented objects.

User	Date	Time	Window	Coaster1	Coaster2	Coaster3	Coaster4	Coaster5	Coffee	Door	Fridge	hotWater	coldWater
User 3	21/09/2015	12:05:54 PM	1	0	0	0	0	0	0	1	0	0	0
User 3	21/09/2015	12:05:58 PM	1	0	1	0	0	0	0	0	0	0	0
User 3	21/09/2015	12:06:16 PM	1	0	0	0	0	0	1	0	0	0	0
User 3	21/09/2015	12:08:43 PM	1	0	0	0	0	0	0	0	0	1	0
User 3	21/09/2015	12:13:35 PM	1	0	1	0	0	0	0	0	0	0	0
User 2	21/09/2015	12:28:27 PM	1	0	0	0	0	0	0	1	0	0	0
User 2	21/09/2015	12:28:51 PM	1	0	1	0	0	0	0	0	0	0	0
User 2	21/09/2015	12:31:01 PM	1	0	0	0	0	0	0	1	0	0	0
User 4	21/09/2015	13:56:17 PM	1	0	0	0	0	0	0	0	0	0	1
User 4	21/09/2015	13:56:33 PM	1	0	0	0	0	0	0	0	0	1	0
User 2	21/09/2015	13:08:39 PM	1	0	1	0	0	0	0	0	0	0	0

Data and the links found amongst objects, allowed for an understanding of how and when interactions happen, and when "friendship" relationships with other objects occur for certain activities. For instance, by detecting when the office's windows have been closed or opened, and by correlating these data with the one collected from the water dispenser, it could be inferred whether a person feels hot and needs to hydrate. A more elaborate system could be trained to identify those patterns and then suggest to the user when he or she needs to drink the recommended 2 litres of water per day. Along these lines, human behaviour can be described by the set of tasks needed to perform an activity, albeit a simple one such a preparation of a hot drink.

4. Discussion and Conclusion

This study has been developed as an exercise in looking at the interactions of human users and instrumented devices towards identifying the correlations that could describe different topics in a pre-established theme in the network. Hence, the testbed provided a framework where identification of individual users from sensor data was possible, by looking at the patterns of activation of the different instrumented devices within a particular timeframe. This of course presents an interesting challenge of identifying all the actions originated by the many permutations of the collected data, but by clearly defining the theme of the network and from the ground truth stated by each of the users, its analysis becomes more manageable. As the theme of the network was defined before hand, it is possible to distinguish between individual topics that contribute to it. By analysing them, additional information from the data can be inferred at later stages, such as amount of water used in the office, number of coffee capsules, and even identification of individual users.

Further work will involve the definition of a taxonomy that allows for theme communication amongst IoT networks, as well as the correlation analysis of sensor data, to automatically allow for the discovery of the Theme. As discussed, clear and common frameworks should be developed to allow for an IoT that supports conversation with other networks, objects and users and in turn assuage the relationships amongst the involved parties.

Some challenges have been identified, such as the repercussions of having objects automatically taking decisions on behalf of humans. For example, in our experimental network, it would be easy to implement a feature were the system makes an online order of coffee or milk as consequence of detecting that the last capsule has been used, i.e., by having an SMS (Short Message Service) message sent to a mobile telephone. This might need to draw on additional information, such as when milk was last bought or the perishable nature of milk: should an order be placed if it was a weekend or a bank holiday and no one would be there to receive the order? When the system infers decisions without full information, problems could escalate. We can see that without proper understanding from the user's perspective of what both the system and user want to do, problems can occur. Hence we propose that through the use of meaningful conversations with identifiable themes, Human-IoT interaction would be less prone to a misunderstanding of their purpose, and more easily adopted for different use cases.

References

Atzori, L., Iera, A., & Morabito, G. (2010). The Internet of Things: A survey. Computer Networks, 54(15), 2787–2805. Elsevier B.V.

Atzori, L., Iera, A., & Morabito, G. (2014). From "smart objects" to "social objects": The next evolutionary step of the internet of things. IEEE Communications Magazine, *52*(January), 97–105.

Berners-Lee, T., Hendler, J., & Lassila, O. (2001). The semantic web. Scientific american, *284*(5), 28–37. New York, NY, USA:

Cervantes-Solis, J. W., Baber, C., Khattab, A., & Mitch, R. (2015). Rule and Theme Discovery in Human Interactions with an "Internet of Things." *To be published in the Proceedings of the British HCI 2015 Conference*.

Fan, T., & Chen, Y. (2010). A scheme of data management in the Internet of Things. 2010 2nd IEEE International Conference on Network Infrastructure and Digital Content (pp. 110–114). IEEE.

Fitbit. (2015). Fitbit. Retrieved December 3, 2015, from https://www.fitbit.com/

Guo, B., Yu, Z., Zhou, X., & Zhang, D. (2012). Opportunistic IoT: Exploring the social side of the internet of things. Proceedings of the 2012 IEEE 16th International Conference on Computer Supported Cooperative Work in Design, CSCWD 2012 (pp. 925–929).

Kortuem, G., Kawsar, F., Fitton, D., & Sundramoorthy, V. (2010). Smart objects as building blocks for the Internet of things. IEEE Internet Computing, 14(1), 44–51.

Ma, H.-D. (2011). Internet of things: Objectives and scientific challenges. Journal of Computer science and Technology, 26(6), 919–924. Springer.

Manat, B. (2014). Towards a smarter Internet of Things : semantic visions. 2014 Eighth International Conference on Complex, Intelligent and Software Intensive Systems, 582–587. Ieee.

Meder, J. (2014). Human Empowerment in a Semantic Web of Things Concept of a semantic platform for connected devices.

Nest Labs. (2014). Nest. Retrieved December 14, 2014, from https://nest.com/

Nitti, M., Atzori, L., & Cvijikj, I. P. (2014). Friendship selection in the Social Internet of Things: challenges and possible strategies. IEEE Internet of Things Journal, 4662(c), 1–1.

Node-RED. (n.d.). Retrieved May 29, 2015, from http://nodered.org/

Perera, C., Zaslavsky, A., Christen, P., & Georgakopoulos, D. (2014). Context aware computing for the internet of things: A survey. IEEE Communications Surveys and Tutorials, *16*(1), 414–454.

Shin, D. (2014). A socio-technical framework for Internet-of-Things design: A human-centered design for the Internet of Things. Telematics and Informatics, *31*(4), 519–531. Elsevier Ltd.

Swan, M. (2012). Sensor Mania! The Internet of Things, Wearable Computing, Objective Metrics, and the Quantified Self 2.0. Journal of Sensor and Actuator Networks, *1*(3), 217–253.

Wang, W., De, S., Toenjes, R., Reetz, E., & Moessner, K. (2012). A Comprehensive Ontology for Knowledge Representation in the Internet of Things. 2012 IEEE 11th International Conference on Trust, Security and Privacy in Computing and Communications (pp. 1793–1798). IEEE.

Yang, R., & Newman, M. W. (2013). Learning from a Learning Thermostat : Lessons for Intelligent Systems for the Home. Proceedings of the 2013 ACM international joint conference on Pervasive and ubiquitous computing (UbiComp 2013), 93–102.

Zhu, F., Mutka, M. W., & Ni, L. M. (2005). Service Discovery in Pervasive Computing Environments. Pervasive Computing, 81–90.