Towards the evaluation of Quality of Experience of Internet of Things applications

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***Abstract*—The widespread diffusion of Internet of Things (IoT) devices has made the evaluation of the performance of IoT applications more and more important as relevant deployments are ubiquitously present in our everyday life activities. However, the plethora of IoT applications is quite vast, so that giving some guidelines on how to conduct this evaluation is very complex in a fast changing setting. The objective of this paper is to tackle the issue of Quality of Experience (QoE) evaluation of IoT applications. First, an overview of current methodologies are provided regarding the QoE assessment of multimedia applications. Second, reasonings are discussed regarding the discouragement of the conduction of Subjective Quality Assessments (SQAs) for the evaluation of the QoE of IoT applications. Third, some solutions for QoE prediction are provided, based on the analysis of the data being collected by IoT applications. The aim is to define some best practices for the design of IoT applications, which focus on the collection of specific user information needed for the prediction of the user's QoE.**

***Index Terms*—Quality of Experience, Internet of Things, Multimedia.**

I. Introduction

The Internet of Things (IoT) is a world-wide network of interconnected objects, uniquely addressable, based on standard communication protocols [1]. Since its conception at the beginning of last decade, it has evolved by incorporating more and more technologies so that different types of devices are part of it: from RFID tags to sensors, from simple actuators to complex wireless sensors networks, from connected cars to wearables. With all of these kinds of objects, IoT covers many different domains of utilization, and several applications exist with heterogeneous requirements and purposes.

Briefly, IoT will be populated by an immense number of devices. Such devices will adopt heterogeneous technologies and standards and will have unequal capabilities in terms of processing, communication and energy availability. However, they will provide services integrated in critical applications involving the continuous monitoring and control of the physical environments in which humans live and operate. Size, heterogeneity, the criticalness of the envisioned applications and the limitations of the resources of the components make the IoT a very complex environment, rich with opportunities and threats. It is unlikely that even the most advanced of the IoT devices will be able to survive and operate effectively in such a context, individually. IoT platforms have then the objective to combine and control the flows of traffic and signals received from different objects, processing in real time and offline the data and take actions, which will impact at the end (hopefully in a positive way) the quality of life of the humans.

In this scenario, the evaluation of the performance of IoT applications is becoming more and more important as relevant deployments are ubiquitously present in our everyday life activities. However, the plethora of IoT applications is quite vast, so that giving some guidelines on how to conduct this evaluation is very complex in a fast changing setting. A few studies related to this issue have been conducted with reference to the Quality of Experience (QoE), which aims at assessing how end-users subjectively perceive the quality of an application or a service [2]. Being user-centric, the QoE provides a more holistic understanding of the system's influence factors with respect to the technology-centric measures of the Quality of Service (QoS) approach. Also, being closer to the user perspective, the QoE better provides indications of to what extent the applications will be used by the users and what will be the real impact on the human quality of life. However, it is also important to consider further quality indicators such as Quality of Data (QoD) and Quality of Information (QoI), which are strictly related to data and information quality processed by smart objects.

In this paper, the QoE evaluation of IoT applications is investigated. First, an overview of current methodologies followed by researchers to assess the QoE of multimedia applications is provided. Second, by highlighting the differences with regard to multimedia applications, the reasons which discourage the conduction of Subjective Quality Assessments (SQAs) for the evaluation of the QoE of IoT applications are discussed. Third, some solutions for QoE prediction are proposed, which are based on the analysis of the data being collected by IoT applications. The objective of the proposed data analysis approach is not only to predict the actual QoE of the users of IoT applications, but also to understand which information, that is not collected yet, may be considered in the design of future IoT applications. The aim is to define some best practices for the design of IoT applications, which focus on the collection of specific user information needed for the prediction of the user's QoE.

The paper is organized as follows. Section II presents related work. Section III discusses the importance of QoD and QoI quality indicators. Section IV provides an overview of current methodologies for QoE evaluation of multimedia applications. In Section V, the reasons which discourage the conduction of SQAs for the evaluation of the QoE of IoT applications are discussed; then some solutions for QoE prediction based on the analysis of the data being collected by IoT applications are provided. Finally, Section VI concludes the paper.

II. Related Work

In the literature, there are only a few works that have started addressing quality evaluation of IoT applications. [3] and [4] focused on QoS evaluation defining an IoT architecture composed of three layers: Sensing, Networking and Application. For each layer, a monitoring module manages the resource allocation as a function of measured QoS metrics: information accuracy, sensing precision and energy consumption at the Sensing layer; bandwidth, delay, throughput and coverage at the Network layer; service performance cost, performance time, load and reliability at the Application layer. Although QoS parameters are important for the performance evaluation of an IoT platform, they should be considered as a function of the quality perceived by the end-user and not only as a fulfillment of Service Level Agreements (SLAs).

In [5], the authors defined the Cognitive Internet of Things (CIoT), a new network paradigm where physical and virtual things or objects are interconnected and behave as agents, with minimum human intervention. The CIoT framework measures three different qualities: Quality of Data (QoD), Quality of Information (QoI) and QoE. The QoD refers to the quality of sensed data, the process of data acquiring and the possible data distribution at the perception/sensing stage. The QoI is a satisfactory metric which tries to concern the information that meets decision makers need at some place, location, social setting and specific time. Finally, the QoE is evaluated from factors belonging to four levels: Access, Communication, Computation and Application. In [6], a layered QoE management framework is proposed, which aims at evaluating and controlling the contributions of each influence factor to estimate the overall QoE of IoT applications. Each layer focuses on a specific QoE domain (set of influence factors), so that the overall quality can be computed as a combination of all domains. A QoE layered framework is also proposed in [7], where the massive amount of quality metrics in the IoT architecture are defined as physical metrics and organized into four layers: Device, Network, Computing, and User interface. Metaphysical metrics are also introduced, which are defined as the quality metrics that users of IoT applications demand. QoE of applications is modeled as a function of physical and metaphysical quality metrics in the IoT architecture.

To the best of authors' knowledge, there are only two works in the literature providing results of SQAs of IoT applications. The first is [8], where the authors focused on the perceived quality in actuators connected to the IoT. They developed a test bed that consisted of an electro-mechanical arm controlled over a packet switched unreliable link. The experiment required users to direct a fixed laser attached to the fixed arm's grabber towards a set of targets. The experimental factors were the average one-way delay, the packet loss and the number of degrees of freedom of the arm. From the subjective quality results, in terms of the Mean Opinion Score (MOS), the authors defined a parametric QoE model that estimates the QoE as a function of the considered experimental parameters. The second SQA regards a vehicular IoT application implemented to verify the applicability of the QoE layered measurement approach proposed in [6]. The IoT vehicle application shows in a multimedia way and in real time the state and the position of the vehicles during driving lessons together with a video showing a view of the roads traveled by these vehicles. Also in this case, parametric QoE models were defined to predict the quality perceived by the users.

III. Quality indicators for the IoT

For multimedia systems and service, the QoE is defined as *"the degree of delight or annoyance of the user of an application or service"* [2]. Factors influencing the QoE are grouped in three categories, namely Human, System, and Context. Human factors consider the property and characteristic of a human user. System factors refer to properties and characteristics that determine the technically produced quality of an application or service (including the QoS). Finally, context factors embrace any situational property to describe the user's environment in terms of physical, temporal, social, economic, task, and technical characteristics.

While the knowledge of these factors may allow to predict the QoE of multimedia services, they may not be enough for the evaluation of the QoE of IoT applications. Indeed, these applications strongly depend on the data acquired by sensors and objects (which can also be multimedia objects) as well as on the huge amount of information acquired and processed to provide specific services. Therefore, two further quality indicators should be considered, i.e., the Quality of Data (QoD) and the Quality of Information (QoI).

The QoD consists of data accuracy, data truthfulness, data completeness, and data up-to-dateness [5]. The data accuracy reflects the precision of collected data. The data truthfulness indicates the reliability degree of the data resource. The data completeness corresponds to the ratio of collected data amount to the amount of all required data. The data up-to-dateness reflects the validity of data to the decision-making, i.e., if the data are too late to assist decision making, it is meaningless. The four aspects jointly determine the overall QoD.

The QoI is defined as *"the body of tangible evidence available (i.e., the innate information properties) that can be used to make judgments about the fitness-of-use and utility of information products"* [9]. The QoI was introduced for measuring the obtained information from sensor networks [10], motivated by the importance that quality information plays in improved situation awareness, effective decision making and action taking. QoI has been then adopted as a quality metric of the IoT in [11]. However, how to model the relationships among these new metrics and conventional QoS and QoE has not been discussed. In [5], QoI is treated as a satisfactory metric because it tries to concern the information that meets decision maker's need at some place, location, social setting and specific time. Existing QoI metric is defined as

$$QoI = Q \times P \times R \times A \times D \times T \times V \tag{1}$$

where Q denotes Quantity, P denotes Precision, R denotes Recall, A denotes Accuracy, D denotes Detail, T denotes Timeliness, and V denotes Validity. All values are normalized into $[0, 1]$ with 1 representing the corresponding best case. In the above metric, Quantity represents how much useful information the decision maker has obtained for a specific task. If all needed information is available, $Q = 1$. Precision here may refer to the proportion of relevant information to all information gathered by sensors, networks or services. On the other hand, Recall refers to the proportion of relevant information without the assistant from sensors, networks or services. Accuracy represents the accuracy degree of information to decision maker's requirement. Note that Quantity, Precision, Recall, and Accuracy jointly characterize the quality of the information Quantity provided. Detail characterizes the complete degree of the information to the decision maker. Timeliness is used to measure the decision maker's timeline along which the information is to be employed. The time delay is the gap between the instant the information is available and the instant the information is employed. Then, the Timeliness can be treated as inversely proportional to the time delay. If the information is available before the decision-maker using it, the timeliness is 1. Validity reflects the trueness of the provided information.

IV. QoE EVALUATION OF MULTIMEDIA APPLICATIONS

QoE of multimedia applications is typically evaluated by conducting subjective quality assessment (SQAs), i.e., standardized tests in which sample people are asked to rate the quality of multimedia contents and their satisfaction with the service. SQAs must follow well defined rules provided by ITU Recommendations such as ITU-R BT-500 [12], ITU-T P.910 [13] and ITU-T P.800 [14], which provide respectively the guidelines to conduct subjective test for assessing the quality of television pictures, multimedia applications and voice calls. Such guidelines include general methods of test, selection of test contents, grading scales, viewing conditions, analysis of the results, etc. Due to the unsuitability of SQAs for real-time monitoring and management of the QoE, objective mathematical models are defined which predict user's perceived quality in function of factors affecting the QoE such as system, context and human influence factors [2]. Valid objective quality models provide quality predictions highly correlated with subjective results.

However, the utilization of objective quality models is limited to scenarios similar to those considered for the SQAs. Therefore, each proposed model can be utilized only for specific applications and conditions. But possible services regarding multimedia applications are quite limited and typically involve the streaming of video and audio contents, whose quality evaluation process is standardized [12]–[14]. The differences among these services generally regard the type of content, the used codec and the considered distortion parameters. For example, in [15] a survey on parametric QoE estimation for popular services is provided. For each specific service (e.g., VoIP, video streaming, IPTV, web browsing, YouTube, etc.), well defined QoE models are presented, which provide quality predictions highly correlated with subjective results and may even be standard models such as the E-model defined by the ITU for VoIP calls [16]. However, as multimedia services evolve, also the models should evolve. For example, current QoE models for video streaming cannot be used to predict the quality of 4K video contents. Further SQAs should be conducted to adapt current models to new video resolution and encoding. Also, there are not yet any QoE models for emerging multimedia applications such as interactive multimedia and virtual reality.

V. QoE EVALUATION OF IoT APPLICATIONS

In this section, the reasons which discourage the conduction of SQAs for the evaluation of the QoE of IoT applications are discussed. Then, a solution for QoE prediction is proposed, sustained by concrete examples, based on the analysis of the data being collected by IoT applications.

A. Analysis of current issues

In the last years, a huge number of IoT applications has been developed for different objectives and services. Some examples of domains of utilization for IoT applications are: healthcare, social, smart home, smart grid, smart city, smart environment, transportation, smart business and logistics, security and surveillance, etc. QoE requirements can be very different with respect to the considered IoT application as well as among IoT applications belonging to the same IoT domain.

In [6], a layered-based approach for evaluating and controlling the QoE of multimedia IoT (MIoT) applications is proposed, in which people are involved as the end-users of the multimedia content. The layered approach was chosen since the objective was to evaluate different categories of QoE influence factors in different layers and then to combine these measures in order to maximize the final QoE perceived by the user using the IoT application. Each layer focuses on a specific QoE domain (set of influence factors), so that the overall quality can be computed as a combination of all domains.

The objective of this layered modelling approach is to provide a model as general as possible which allows to consider and combine all the factors needed to evaluate the QoE of an IoT application. However, to practically predict the QoE it is necessary to conduct ad hoc SQAs which depend on the specific IoT application and scenario considered. Therefore, on the basis of the huge number of different existing (and future) IoT applications, in this authors' opinion it is not advantageous to conduct SQAs for the evaluation of the QoE of IoT applications. Indeed, even if objective models will be derived from SQAs, these would be valid only for specific IoT applications and utilization conditions. This is the case of the models defined in [8] and [6]: although quality predictions are highly correlated with subjective results, the utilization of these models is strictly limited to the specific scenario from which they are built.

Moreover, IoT applications quickly evolve with the time (e.g., they may include additional sensors and functionalities) and the defined models should evolve accordingly requiring the conduction of new SQAs. Additionally, currently there is not any recommendation which describe how a SQA should be conducted for the evaluation of the QoE of an IoT application. This is probably due to the ample number of types of IoT applications. Furthermore, as discussed in Section III, the QoE of an IoT application requires the evaluation of new quality indicators besides the QoE influence factors currently considered for the evaluation of the QoE of multimedia services (system, human and context influence factors). Indeed, QoD and QoI are quality indicators strictly related to the quality provided by the data collected by the sensors and the information processed by the IoT application. Also, differently from multimedia applications, IoT applications may require the user to have at least basic computer skills to install and set objects in IoT platforms (e.g., lifely [17], Lysis [18], carriots [19]). Platform characteristics such as user-friendliness and ease should also be considered for QoE evaluation in these cases.

B. Proposed solution and open challenges

On the basis of the considerations discussed in the previous section, here a different approach for QoE prediction of IoT applications is proposed, which consists in the analysis of the data and information collected by the IoT application. Indeed, current IoT applications are already collecting many information about their users and this information can be useful to understand the behavior and satisfaction of the users.

In the following, some examples of information and data that can be used to understand users' QoE are discussed:

- *usage data*: data regarding the usage of the application is fundamental to understand the satisfaction of the user. From usage data the user behavior can be investigated, i.e., when the user uses the application, which functionalities are used, how much time the application is used, etc. In the worst case, if the user uninstall the application, she has surely had some problem with it and it is very important to understand the reasons. An e-mail may be sent to the user asking the reason why she uninstalled the application (just a simple question with common multiple answers to be selected) or the reasons can be derived from user's behavior (e.g., the user used to quit the application while using a specific function that she did not like or because of insufficient network resources that did not allow to receive the desired service quality).
- *user actions*: actions of the user can be an indicator of the perceived quality. As a practical example, consider BusFinder, an application which allows people to buy and validate bus tickets with their smartphones [20]. If it results from collected data that the user bought a ticket and after a while she validated it, probably she had a good experience with the application. On the contrary, if the user bought a ticket but she did not use it, maybe she encountered some issues that disappointed her expectations. In this case, some new functionalities can be thought such as a pop up which asks the user why she have not used the ticket yet, to understand whether there are some problems with the app or it is just the user's choice.
- *unsatisfactory service*: sometimes it can happen that an IoT application is not able to provide the needed service to their users. For example, consider a carpooling application such as CLACSOON [21], which allows to find or offer a ride with other people in real time. By analyzing user data, information regarding users looking for a ride may be correlated with information proving that those users found the ride. Indeed, it is highly likely that if a user never or rarely finds the needed ride with that application, she will quit that service in the future. Therefore, by analyzing this data it is possible to concentrate marketing actions in those places where the app is not used to offer rides in order to strengthen the app service to the users.

The objective of the proposed data analysis approach is not only to predict the actual QoE of the users of IoT applications, but also to understand which information, that is not collected yet, may be considered in the design of future IoT applications. Moreover, the aim is to identify even some functionalities which are not essential for the correct operation of the IoT application but that may help to investigate the quality perceived by the users. As a final result, it would be very important for the QoE research community to define some best practices for the design of IoT applications, which focus on the collection of specific user information needed for the prediction of the user's QoE. As an example, famous best practices have been provided by jacob Nielsen in the 1995, and are still valid today, regarding usability heuristics for user interface design [22].

VI. Conclusion

In this paper, the issue of Quality of Experience (QoE) evaluation of IoT applications is investigated. First, an overview of current methodologies are provided regarding the QoE assessment of multimedia applications. Second, reasonings are discussed regarding the discouragement of the conduction of Subjective Quality Assessments (SQAs) for the evaluation of the QoE of IoT applications, because of the ample number of different types of IoT applications existing. Third, some solutions for QoE prediction are provided based on the analysis of the data being collected by IoT applications. The aim is to define some best practices for the design of IoT applications, which focus on the collection of specific user information needed for the prediction of the user's QoE. Future work regards the definition of these best practices as well as the utilization of useful data and information collected by IoT devices for QoE evaluation.

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