A Sensor-Enabled Rule Engine for Changing Energy-Wasting Behaviours in Public Buildings

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***Abstract*—Activity of occupants in public buildings is a key source of energy wastage, yet hard to track and cope with. In this paper, we present a challenge-based logic in a gamified approach to alter energy-wasting behaviour. Each challenge is expressed as a rule, the accomplishment of which is verified on the basis of a sensor and energy metering infrastructure. We employ a challenge-focused cost-effective instrumentation approach regarding sensors and energy metering equipment installed in the buildings. A event-based processing approach validates user compliance to the various rules on an effective and scalable manner. Finally, we exemplify the operation of our system by walking-through the execution of a specific challenge.**

I. Introduction

According to Buildings Performance Institute Europe (2011) [1], public buildings consume 40% more energy than residential buildings, while buildings overall consume 40% of the total energy (and electricity) consumption. Public offices constitute 23% of the non-residential sector and are responsible for 26% of its energy consumption. User activity is an important driver of this consumption [2], yet one that is hard to cope with. Occupants in public office buildings lack financial incentives to save energy; neither do they pay the bill, nor spare the time for energy conservation, as they are pre-occupied with their tasks. Even when intrinsic motivation towards sustainable behaviour is present (i.e., altruism, energy awareness, personal norms, etc.), people often lack the knowledge and the ability to exert such behaviour.

Much work has been recently done based on gamification approaches [3], [4], [5], [6], [7] to address energy conservation in public buildings. Gamification, in general, is intended to tap into people's intrinsic motivations, increase user engagement and achieve system objectives through a playful experience. However, these gamification approaches often rely on an comprehensive sensor and metering infrastructure for tracking user activity [4], [5], [7]. Firstly, according to ethnographic studies in public buildings [8], such an instrumentation approach is not desirable due to privacy concerns of building occupants. Secondly, such approaches are not economically sustainable.

In this paper, we follow a different approach: we organize our gamified approach around challenges. Each challenge aims to challenge a specific energy-wasting behaviour of public-building occupants. The overall game objective is to reduce the energy-wasting actions. Each challenge may be undertaken by a user on a voluntary basis. Challenge accomplishment awards some points; it is verified by means of an instrumentation approach that employs sporadic sensor and energy metering infrastructure at the building, and sensors at the user smartphones, specifically targeted to monitor challenge-specific user actions. Sensor events are generated upon user actions that are relevant to energy-wasting actions, while our system is oblivious by nature regarding other user actions. Each challenge is implemented as a rule and compliance checking of the user actions to the rule is performed by a proprietary rule engine on a complex-event processing manner.

Only players undertaking challenges get awarded points, while players belong to teams that compete each other for vanity. Points get awarded to all players that have undertaken a challenge and not violated the respective rule. We describe our sensor infrastructure and energy metering infrastructure and our event-driven rule processing approach and demonstrate its effectiveness and scalability by walking-through the execution of a specific challenge.

The remainder of this paper is organized as follows: In Section II, we overview the related work. In Section III, we describe our game approaches and some indicative challenges. In Section IV, we overview our system implementation. In Section V, we present the list of sensor events and the format of the messages exchanged in the system. In Section VI, we describe our rule engine and the processing of event chains. In Section VII, we present the execution of a sample challenge to exemplify the effectiveness, the scalability and the impact of our approach. Finally, in Section VIII, we conclude our work.

II. Related Work

There has been some prior work on gamification approaches for conserving energy in public office buildings [3], [4], [5], [6], [7], [9]. Cowley et al. [3] describe a game framework

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aimed to teach energy efficient knowledge and behaviour to users of public buildings by introducing Behavlets (i.e., action-resourve-outcome triplets for educational purposes on energy savings). However, energy-saving actions themselves are not part of the game in [3], as opposed to our approach. Simon et al. proposed Climate Race [4], a pervasive game addressing office workers, where energy consumption is related to the activities of each player by observing corresponding behaviours through a comprehensive sensor and plug-level metering infrastructure, as opposed to our more cost-effective solution. Also, the GreenSoul approach [5] focuses on the reduction of the energy consumption in public buildings by means of a thorough sensor infrastructure that provides recommendations to occupants regarding energy savings. A virtual pet game designed for energy use reduction in a commercial office setting was introduced in [6], where device-specific energy consumption was reflected in the fitness of virtual pets. Our gamified app has far more ambitious goals than [6] in the sense that it aims to change a vast range of energy-wasting behaviours at work. In [7], they describe a gamification approach with similar goals with ours, yet with different game scenario and technological approach. As opposed to our approach, no challenge-based logic or event-based rule processing is employed in [7], while user actions are constantly tracked. Finally, while in [9] we describe the objectives of ChArGED and our overall game setup, in the present work we focus on the implementation of the game challenges by means of rule processing.

There has also been some prior work on employing a rule-processing approach for energy conservation in public buildings. In [10], the authors employ rules for providing personalized recommendations to occupants of public buildings for reducing energy consumption. Another rule-based approach with similar objectives in school buildings was proposed in [11]. A rule-based semantic architecture for enabling users to define and enforce automation policies has been proposed in [12]. Two rule-based approaches for enforcing energy-saving policies were proposed in [13], one based on production rules and the other one using defeasible logics.

Finally, several powerful (including open source) rule engines exist, such as Drools (drools.org) and Jess [14], and complex event processing engines, such as WSO2 CEP (wso2.com/products/complex-event-processor) and Proton CEP (github.com/ishkin/proton), but they have a steep learning curve and it is hard to extend the rule set in them.

III. The Game Approach

We employed the Rapid User Centered Design (Rapid UCD) process and conducted on-site visits, ethnographic studies and online surveys to find user requirements. According to our findings, described in [9], [8], a number of energy-wasting actions may occur in pilot buildings, such as:

- Windows may be opened, when A/C is on.
- Lights may be left on in unused spaces.
- PCs and monitors may be left on after work.
- Lifts may be used instead of the stairs.
- Printers/photocopiers/coffee machines may be left on after work.

Note that in this working environment, many of the user activities that consume energy are part of their everyday job tasks and are thus *inelastic* in nature. Thus, we focus on changing the behaviours of employees that unnecessarily waste energy. To this end, we employ a gamified approach where employees play on a per-challenge basis. One or more game challenges are defined for avoiding each different energy-wasting behaviour. An employee may undertake a challenge and upon its accomplishment, she/he gets awarded a number of points. Employees belong to teams that compete against each other for points. The winning team is announced at a leaderboard and receives a special badge.

Our solution is being developed iteratively with the end-users engagement during the analysis, design, development and validation phases in public buildings located in 3 different countries: Luxembourg (Muse National d'Histoire et d'Art), Spain (EcoUrbanBuilding, Institut Catal d'Energia headquarters, Barcelona) and Greece (General Secretariat of the Municipality of Athens). In order to address the diverse user requirements of the aforementioned sites, two types of challenges will be included in the Mobile App:

- Personal challenges: They may be undertaken by individual players and their accomplishment depends on individual actions. Their outcome is mirrored on the players progress in the game.
- Team challenges: They may be undertaken by an individual participant, however, their accomplishment is determined by the actions of all members of the team of that individual participant. Their outcome is mirrored both on the personal and the team progress in the game.

Challenges may span different time periods, e.g., daily, weekly or even monthly. Indicative challenges are the following:

- "Use the stairs, instead of the lift"
- "Turn-off lights upon leaving room": This is mainly a team challenge and it is accomplished when the last person leaving the room turns the lights off.
- "Keep windows closed, while A/C is on"
- "Turn off PC/printer/coffee machine upon leave"
- "Turn PC off when away from desk for more than 30 minutes"
- "Shift meeting time": This applies to sites that employ a solar micro-generation system, such as the pilot site of the Municipality of Athens in Greece. This challenge is one of a special category of challenges, aimed to *shift*, otherwise irreducible loads towards time zones within the working day where the net energy load is minimized.

IV. System Overview

Our system consists of four main groups of functional blocks: The Data/Core Backend is responsible for providing an environment in which sensor and energy-measurement data, devices and users are stored and managed. It is mainly implemented upon the open-source SiteWhere IoT middleware

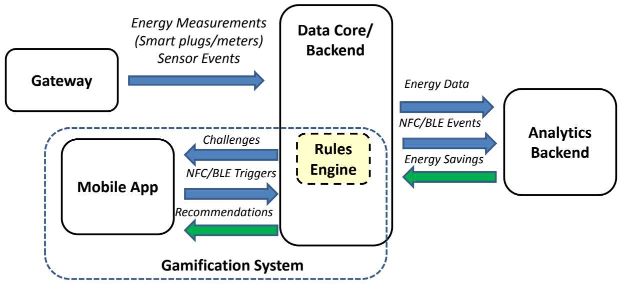
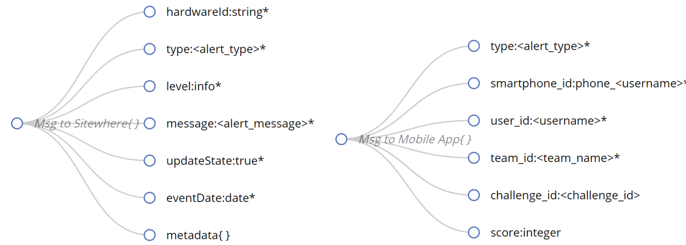


Fig. 1. System overview.



(a) (b)

Fig. 2. (a) JSON schema of message to mobile app. (b) JSON schema of message to Data/Core Backend.

(sitewhere.org). The Gateway for acquisition, filtering and forwarding of energy use and sensor data to the Backend system. The Analytics Backend component is responsible for detecting energy-saving actions and opportunities, and delivering them to the Gamification System. Finally, the Gamification System is responsible for processing sensor data, energy-saving events and opportunities to make decisions as per the evolution of the game for each user, i.e., determine challenge accomplishment, and provide personalized recommendations to the user for energy saving. The mobile app, also part of this group, acts both as an interface between the user and the rest of our system updating the user with the current game state and as a sensor platform providing sensor data to the Data/Core Backend about the users behaviour towards the fulfillment of undertaken energy-saving challenges. We also employ 3^{rd}-party systems for solar-power microgeneration forecasting based on weather predictions and historical weather data for a specific location. This forecasting is send to the Analytics Backend and the Gamification System for calculating the target periods for time-shifting actions (e.g., those where energy microgeneration minus consumption is maximized) and for providing the users with the corresponding feedback respectively.

We employ an energy metering infrastructure comprising N-channel smart meters (i.e., meters capable of metering multiple electrical circuits) and smart plugs. N-channel meters are employed for measuring non-plug loads, e.g., lighting, A/C, lifts, etc., and plug loads associated to a group of up-to-four office desks. Smart plugs are employed for shared office devices, such as printers/photocopiers, coffee machines, etc.

In order to associate the energy consumption of each device to particular occupants at the public building, we also employ a sensor infrastructure. Bluetooth Low Energy (BLE) beaconing devices (Estimote beacons) are placed at office areas and in the lifts for detecting presence at these areas. The distance of a smartphone of an occupant from a BLE beaconing device can be estimated based on the received power at the phone; this information is forwarded by the smartphone to the Data/Core Backend System. Also, an NFC sticker is associated to each device (and lighting switch). The building occupants are requested by the game to report their energy-saving actions to the system by swiping their phone to the various NFC stickers, in order to get awarded a number of points for their conserved energy. Also, an NFC sticker is placed in the middle of the stairs between two floors, in order for people to claim to our system that they have taken the stairs, instead of the lift. Moreover, a (Fibaro) switch sensor is placed at every window of the building, in order to check if the windows are open, while A/C is on. Finally, a (Fibaro) 4-in-1 Sensor (Temperature, Humidity, Luminosity, Motion/Presence) is also employed per area, in order to aid in the association of energy saving actions to particular individuals and in the discovery of energy-saving opportunities, and to monitor the comfort conditions in the building.

The associations of circuits to devices, devices to building layout, smart plugs to devices, devices to NFC IDs, switch sensors to windows, BLE beaconing devices to rooms and 4-in-1 sensors to rooms are stored in the Data/Core Backend.

V. Sensor Events

Our sensor infrastructure generates a list of events, namely:

- BLE events that convey whether user entered/left room or building.
- NFC events that convey the instantaneous association of a user to a device, e.g., PC, printer, lift, etc.
- Switch sensor events that notify the system whether a specific window has been opened or closed.

The JSON schema of an event message to the Data/Core Backend is depicted in Fig. 2a. The *hardwareId* field contains the device id inside Data/Core Backend that the alert is sent for. The *alert_type* field depends on the sensor, i.e., NFC, BLE, 4-in-1, that generated the event. The *message* field carries a message that is specific to the type of the alert and describes its nature. The *eventDate* holds the date and time of the event, while *metadata* is an optional field that may carry additional information about the alert, describing the event in more detail. Events are stored at Data/Core Backend, get pre-filtered and those relevant to the Mobile App are forwarded to the Gamification Backend.

Also, the Gamification Backend conveys data and alerts to the Mobile App for updating the game frontend according to the changes at the game state. The JSON schema of a message to the Mobile App is depicted in Fig. 2b. The *type* field conveys the type of message or alert, while *smartphone_id* is the smartphone of the user that the message is sent to. *user_id* and *team_id* carry the username and the team name respectively of the user. The *challenge_id* field is optional and conveys the challenge that the alert corresponds to (if

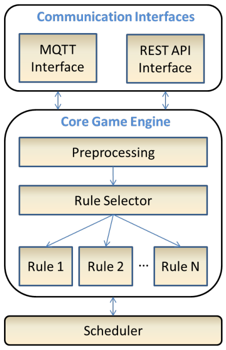


Fig. 3. Rule-engine internal architecture.

applicable), while *score* is another optional field with the current user score (if applicable).

VI. Challenge Accomplishment Validation

A. Rule-Engine Overview

The Game Backend implements the game rules logic that is going to be used in order to decide the progress of a user in the game, update the user scores and leader board, and keep track of the currently accepted/available challenges of a user. It has been implemented in Java and interfaces with SiteWhere via MQTT and REST. All the communication between the software components happens through SiteWhere.

Whenever an event is sent to SiteWhere from a device (i.e. a measurement or an alert), the event is stored and forwarded to a predefined MQTT topic which is listened by the other software components. The Game Backend listens to events sent to SiteWhere that describe the users behaviour and its results (such as NFC swipes, user location updates and energy updates), processes the data and determines the user progress with respect to the challenges that have been accepted or schedules delayed or recurrent processing. The processing performed by the Game Backend is not necessarily tied with the specific time an alert has arrived. Separate logic can also be triggered or executed at a different time to check/update the game progress and provide updates to the other system components. Internally the Game Backend consists of three different subcomponents. The first one is responsible for interfacing with the rest of the system through MQTT and REST. This interface is used to receive/request and update data according to the results of the rules. The second sub component is the core engine that implements the game logic. It consists of a preprocessing component which handles the incoming messages and accordingly selects the relevant rule out of a list of rules. These are the main parts of the game logic and game challenges or actions that should be performed. One such rule determines that at the end of the week the challenges which have not been completed should be identified and released if they have been assigned to any user. The third subcomponent is the scheduler. Its main use is to schedule delayed rules that should be scheduled for the future or executed at specific time intervals (i.e. every day, every week, etc.). New rules can be added as needed to incorporate new challenges. A separate submodule allows easily adding rules, thus ensuring the scalability and continuous enrichment of the game challenges. It organizes rules in a specific structure by inheriting from an abstract class Rule, which defines a common interface as well as implements common functionality.

B. Event-based rule processing

The whole operation of event-based rule processing is divided into two stages: (i) rule matching and (ii) rule execution. We describe these two stages separately below.

1) Rule Matching: Rule matching, depicted in Fig. 4, concerns the selection of the appropriate rule that matches a sensor event sequence that is sent to the Data/Core Backend by the Gateway. Assume that a new event (i.e., alert) arrives at the Data/Core Backend. This alert may have come, either from the smartphone of a player as a result of an NFC swipe or a BLE proximity detection, or from another sensor deployed in the building, such as a temperature (a.k.a. 4-in-1 sensor) or a window switch sensor. For each event, a new sub-process is started, in order to perform the necessary processing. Recall that the events are received via MQTT as JSON messages with a specific structure, as depicted in Fig. 2a. First, the type and message fields are parsed to identify whether the alert is of a type relevant to the current set of rules. (Recall that the set of rules can be dynamically updated, according to the challenge definitions). If not, then the sub-process takes no further action and exits. Subsequently, the Game Backend tries to match the event to a specific rule. To this end, current unprocessed event chain sequence (i.e., the current state) is retrieved from the database. Additionally, event metadata are linked to static data associations in the database through SiteWhere, as needed, to derive new insights, such as the location in the building where the event was generated, the user association with the device to which the event corresponds, etc. If the new alert with previous event-chain state can be matched to a rule, then the rule-execution stage starts, otherwise the current event state is updated in the database and the sub-process exits.

2) Rule Execution: If an existing game rule is matched to the current event, as explained in the previous subsection, then we move to the rule resolution stage where the specific rule is instantiated and started. At this stage, additional data are retrieved from the database that will be used during the processing (such as prior relevant events, whether the corresponding challenge was already accomplished or not for the day, etc.). Subsequently, if input from the Energy Analytics Backend is needed, then a relevant request is made to it. The Energy Analytics Backend will asynchronously respond with a new message containing the necessary information through MQTT via SiteWhere, which will be picked by the Game Backend. If the rule exectution needs to wait for additional events, then the rule state is stored in the database and the sub-process exits. The rule continues its execution when the required events arrive; then, rule state is retrieved from the database. After all necessary events have arrived for a specific rule execution, we check whether all the conditions of corre-

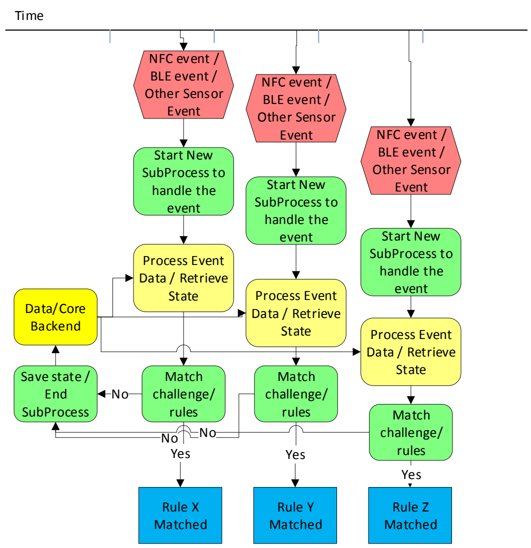


Fig. 4. Event-driven process chain for rule construction.

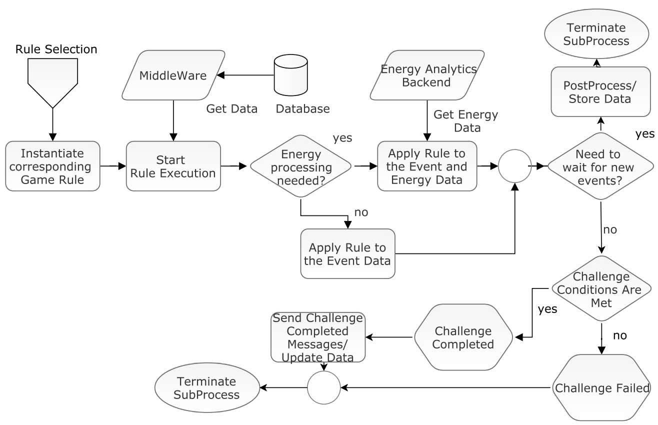


Fig. 5. Flowchart of the rule execution.

sponding challenge are met. Finally, the sub-process updates the database through SiteWhere and the Mobile App on the smartphone(s) of the players or teams that had undertaken the challenge about its accomplishment or failure and assigns points accordingly.

VII. Challenge Implementation and Impact

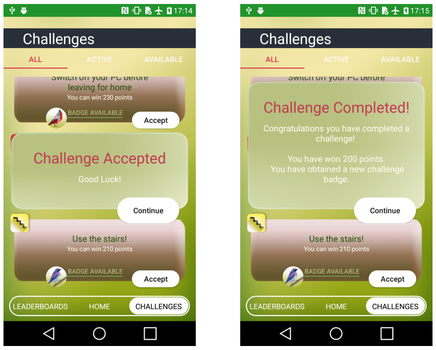
In this section, we describe the implementation of the system by explaining the execution of a single challenge. We employ the challenge "Switch off the PC if leaving the desk for more than 30 minutes".

Each player has a BLE beaconing device near their desk which is used to monitor their proximity to it. The BLEs are configured, depending on the building layout, to transmit signals to a small radius around them (from less than a meter to a few meters). The challenge is activated when a player accepts it on her/his smartphone, as shown in Fig. 6a. After the challenge has been undertaken by a user, BLE beaconing messages are processed by her/his smartphone to check if the user has left her/his desk. If the user has left her/his desk (i.e., a beacon message from another BLE beaconing device is received or the estimated distance to the BLE beaconing device near the user desk has surpassed an upper threshold), then a BLE alert is forwarded via SiteWhere to the Game Backend. This contains details including the smartphone identifier, username and identifiers of the current and previous BLE that was detected by the app. This alert is stored in the database and then forwarded to the Game Backend. Since we have the previous and the current BLE ids, we can detect if the user is returning or leaving their desks. We consider these two cases separately below:

- *Case 1 - User Leaves Desk:* In this case (denoted as Case 1 in Fig. 7), when the previous BLE id (received in a respective alert message) was the one near the user desk, while the new one refers to a random BLE beaconing device in the building (or an empty value, which means that no signal is detected, as the user is out of range of all known BLEs), then the Game Backend will send a *Location Update - User Left Desk* message to the SiteWhere database logging the event. If for the next 30 minutes the user has not returned to her/his desk (which can be detected by the message produced in Case 1), then a new message *Location Update - User Away from Desk* is generated. This message is sent via SiteWhere to the Game Backend (rule engine), which retrieves energy data from the Energy Analytics Backend, in order to check the power consumption at the user desk, since the user left. The power drop (if any) is calculated by the Analytics Backend and forwarded back to the Game Backend. If this power drop is above a predefined threshold, which is selected according to the average electricity consumption of a normal PC (e.g., 40W in idle state, 80-250W when running), it is deduced that the PC has been switched off. The Game Backend then completes the challenge by sending a challenge status message (i.e., accomplished or failed) to SiteWhere to be stored under the user entry and the game state data are updated. Specifically, if the challenge is accomplished, then a number of points specific to this challenge is awarded to the user along with a specific badge. Finally, the Mobile App of the player gets notified about the game state updates.
- *Case 2 - User Returns to Desk:* In this case (denoted as Case 2 in Fig. 7), the previous BLE id (received in a respective alert message) can be any BLE beaconing device that was detected, which is not the one near the user desk, while the current is the one on the desk. Then, the Game Backend deduces that the user has returned to the desk and sends a *Location Update - User Returned To Desk* message to SiteWhere database with the specific timestamp.

Fig. 6b depicts the case where the user is notified that the challenge is accomplished. Note that throughout the execution of this challenge, no user activity tracking takes place, as sensor events that do not match the rules of the undertaken challenge are dropped.

The expected energy-saving impact of a challenge is related



(a) (b)

Fig. 6. (a) Screenshot from the Mobile App upon challenge selection. (b) Screenshot from the Mobile App when challenge accomplished.

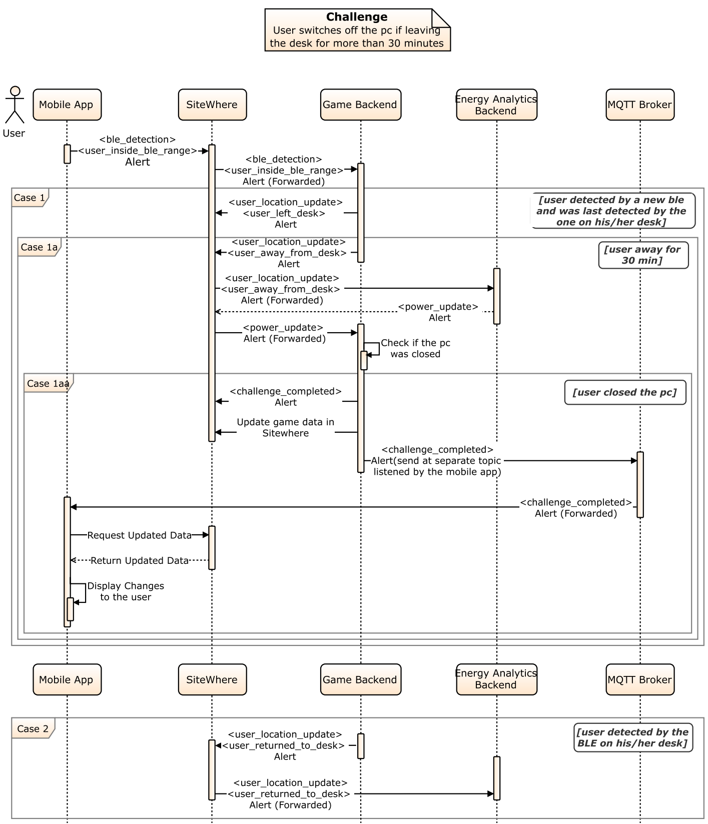


Fig. 7. Sequence diagram for the execution of challenge "Turn PC off when away from desk for more than 30 minutes".

to its targeted energy-wasting behavior. For example, for the aforementioned challenge, the maximum achievable energy savings are $8h \times 40W$, because, in the worst case, supposing that the employee left the office immediately after going to work, the PC would remain idle for 8 working hours (supposing that the PC is shut down after work).

VIII. Conclusion

In this paper, we present the event-driven processing approach to implement the gamified approach of project ChArGED, in order to save energy amenable to user activity in public buildings. Each game challenge aims to change a specific energy-wasting behaviour and internally is represented as a rule. We explain that accomplishment or failure of a challenge on behalf of a user or a team of users is determined by a rule engine based on sensor events. Our implementation approach is extensible and scalable to incorporate additional (even more complex) challenges (as new rules) and additional sensor events. As a future work, we plan to run experiments with real users in the 3 pilot sites of ChArGED to assess the performance and scalability of our system in terms of rule-processing time and latency.

Acknowledgment

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