A Collective Awareness Platform for Energy Efficient Smart Buildings

Ioannis Chatzigiannakis
Computer Technology Institute & Press "Diophantus" and Sapienza University of Rome
ichatz@cti.gr

Dimitrios Amaxilatis
Computer Technology Institute & Press "Diophantus" and University of Patras
amaxilat@cti.gr

Spyros Livathinos
Computer Technology Institute & Press "Diophantus" and University of Patras
livathinos@cti.gr

ABSTRACT

Building Energy Management Systems (BEMS) are mature computer-based systems that manage, control and monitor different building technical services (such as heating, lighting etc.) and the energy consumption of devices used by the building. In the recent years, significant efforts have been made towards the integration of sensor devices and embedded computing systems with the Internet, thus transforming BEMS into a new era of Internet Buildings. Smart buildings can learn and even anticipate the needs of a buildings' occupants, including their preferences for light, temperature and other services, resulting in energy savings through targeted supply. In this work we argue that in such future buildings, it will be simply infeasible to expect individuals to be aware of the full range of potentially relevant possibilities and be able to pull them together manually. We thus propose a system that proactively guides users' interactions based on their preferences and constraints. We develop a collective awareness platform where the control of the smart building is balanced between the people and machines. We present the basic design principles, the implementation details and our experimental findings after evaluating our system in a real-world testbed.

Keywords

Internet of Things, Smart Buildings, Human-Agent Collectives, Experimental Evaluation

1. CAPTURING USERS' OPINIONS

In many occasions the environmental conditions of rooms (e.g., heating/cooling, lighting) are managed by multiple selfishly behaving entities. For example, in a large workspace with many individual (open-air) offices sharing it, with their own heating/cooling devices, each employee i would desire to have a particular level s_i of temperature. Of course, setting up one's own device to a particular temperature would directly affect the working conditions also of the neighboring working spaces. Therefore each individual, apart from her own desire, also takes into account the settings of the neighbors' devices, in order to set her own device's actual temperature to a value z_i. For example, in a particular room with two co-workers, a stubborn one would insist on setting her own device to her desired temperature s_i, while a more altruistic worker would somehow weigh her own desire with the co-worker's announced setting of temperature, as a compromise of both workers' final decisions.

The level of sensitivity of an individual to the other individuals' decisions depends both on their relative locations and their "social structure". For example, in a room of co-workers one might be more sensitive to an individual she likes than to another individual she rather dislikes. On the other hand, irrelevantly of the individual's preferences to them, the decisions of individuals located far away (e.g., in separate working spaces, whose heating/cooling settings do not have an impact on her own workspace) would not affect her final decision at all. It is even possible that an individual has no access to the decisions of other individuals located far away from her.

In any case, given the location of the workers in a particular working space and their social structure, each individual would then somehow selfishly decide the level of temperature for her own device. Depending on how the individuals redefine their own decisions based on other individuals' decisions (e.g., best responses, given a particular objective per individual) the whole system will have to reach a common temperature setting. The major concern for the whole building, is the effect of this (absolutely human) selfish behavior, either on the aggregate level of satisfaction for all the workers in the same building, or on the energy consumption of the equilibrium state, compared to the corresponding "optimum" (but probably unrealistic) choices of decisions by the system rather than the workers themselves.

2. HIGH-LEVEL ARCHITECTURE

The proposed system operates in 3 layers: the first layer is comprised by the WSN, i.e., wireless 802.15.4 devices equipped with a range of sensors and actuators that control individual lighting of rooms (e.g., the lights at the ceiling and at the deskops) and the thermostats. The devices communicate with the 2nd layer (the gateway) using the Constrained Application Protocol (CoAP), an IETF CoRE proposed standard dealing with Constrained Restful Environments. Essentially the Gateway nodes are simply bridging the WSN network with the Internet forwarding request to actuators,

PCI 2015, October 01-03, 2015, Athens, Greece

DOI: http://dx.doi.org/10.1145/2801948.2801993

replies to clients.

Finally at the top, third, layer is comprised by the human-agents collective that interfaces with the humans via their smartphones and communicate between them in order to implement the BEMS logic. A key element of our approach in developing human-agent collectives is the fact that smartphones have evolved to multi-core computational platforms with wireless multi-access capabilities and a large range of embedded sensors, enabling a plethora of services and applications. It is therefore a distributed BEMS application that based on the reported sensor readings and the opinions of the users, invokes actions or generates notifications and alerts to building administrators.

We use the smartphones to identify the location of the users within the building and let them provide their settings for the luminosity and heating for each office separately. Via their smartphones, users input their opinion regarding the "significance" of the settings of the other people working on the same working space. The user settings are stored in the smartphone in a privacy-preserving way so that the individual opinions are not accessible by the other users.

The presence of a user within a building room is communicated to the other smartphones in the room. Given the settings of the users for the environmental conditions of their working space, and also by taking into consideration the weights of the people towards the opinion of their office co-workers, the smartphones of the users coordinate in order to agree on a common set of environmental settings for the room. Recall that each person is asked to rank the opinions of their office co-workers. Here we assume that the opinion of each individual is ranked first, i.e., personal opinion has the highest ranking in the office.

Based on the opinions provided by the users of the real-world experiments, we identify two different scenarios for the ordering of the individual opinions:

- The user provides an ordering on the opinions of the other users working on the same office space.
- The user considers all the opinions of the other users of the same office space as having equal value (no ordering provided).

3. REAL-WORLD EVALUATION

We strongly believe that developing systems for future systems requires the evaluation in real-world conditions. For this reason we assess the performance in the building of CTI that utilizes more than 500 sensors and 70 actuators installed throughout the building that are used to (a) monitor condition inside the rooms, including parameters such as temperature, light per room and also per office desk; and (b) control desktop lights, room (individual) lights and HVAC temperature settings. Our evaluation involves 30 people working in 9 different rooms (of various size). After a period of 2 weeks, we assess the ability of the system to collect the individual opinions of the users and provide efficient methods to compute the optimal settings for the building.

Based on the values inserted via the smartphone application, we collect the value in order to analyze the individual settings. Note that this centralized analysis is done only for the purposes of the experimental evaluation of the system. We use three different approaches to analyze the data: average-value, standard deviation and pareto frontiers. Remark that our opinion collection infrastructure can support other types of functions for computation of aggregates.

Room	Simple	Opinion-based	Savings
0.I.2	3.0	2.48	↓ 17.33%
0.I.8	3.33	3.26	↓ 0.02%
0.I.9	1.0	1.0	↓ 0.00%
0.II.5	0.67	0.56	↓ 16.41%
0.II.6	3.67	3.07	↓ 16.34%
0.II.7	4.67	3.4	↓ 27.19%
3.I.2	3.5	3.0	↓ 14.28%
3.I.3	4.0	3.41	↓ 14.75%
3.I.6	4.0	3.33	↓ 16.75%

Table 1: Level of Luminosity as computed by simple and opinion-based algorithms and cost-savings percentage achieved

The real-world evaluation provides very valuable feedback. First of all it is evident that the users have different opinions regarding the ideal settings for their working environment. In some shared spaces we observe similar opinions, while in others the opinions are diverging. However, even in offices where the users have different opinions, a simple-averaging algorithm provides a reasonable setting for the room luminosity. Therefore a simple-strategy algorithm can give settings that are easily applied in practice.

Another observation is related to the technical infrastructure available for controlling the lighting of the offices. Consider that in order to adjust the lights such that a low intensity is achieved, we need to keep only 1 or 2 lights switched on within the office. In offices where all occupants of the office are requesting a low-intensity lighting for the room, it is not enough to decide the total number of lights that should be activated, but also which ones exactly. If we choose a light that is on-top of one of the working desks, then the luminosity observed for the particular user will be higher than that of the others.

We compare the values computed by the agents with the simple averages. We observe that in all cases, taking into consideration the individual ordering on opinions of the other users, we lead to room settings that are lower (e.g., in terms of intensity) even in rooms where the deviation among the opinion is high.

We observe that in most rooms, the values for the standard deviation are higher for the weighted-average algorithm. For those rooms that the opinions of the users are similar (i.e., the standard deviation is low) the room-level settings are indeed justifiable. However, even in the rooms that the opinions are diverging (i.e., the standard deviation is high), again, the room-level settings are reasonable (for the human observer). This observation leads us to consider notions of "fairness" in terms of selecting room-level settings in a way such the individual user settings are respected.

4. ACKNOWLEDGEMENTS

This research has been co-financed by the European Union (European Social Fund – ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) - Research Funding Program: Thales. Investing in knowledge society through the European Social Fund.