Home Energy Saving through Wireless Sensor Networks

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ABSTRACT
This paper presents an Home Automation system based on Wireless Sensor Networks (WSN) that allows managing and saving the energy consumption of home appliances.

1. INTRODUCTION
According to recent studies [2] energy consumptions are increasing year after year, and if effective energy saving policies will not be adopted, in 2030 they will rise by 28% on 2006 value. The residential sector, in particular, accounts for an increasing percentage of the total consumption which is now above 27.5% (source Earthtrends). These predictions have recently drawn the attention of the research community as well as of the industry world to a new generation of home automation systems for energy saving ([5], [3]).
In this paper, we present an integrated system currently under development within the European project AIM [1], for profiling and reducing home energy consumption. We focus, in particular, on the key role played by wireless sensor networks to automatically control home appliances according to users habits. To create a system where user doesn't need to waste a lot of time in complex settings of system parameters, one of the challenges of AIM project is to automate the set up of a part of these parameters with a system able to predict actual user preferences on the basis of previous observed behavior. This is the main role of the sensor network that senses physical parameters estimating user behavior for future periods and adjusting prediction in real time. On the basis of this information the AIM system is able to best schedule tasks for every appliances, for example heating the room at the desired temperature before the user come in.

2. WIRELESS SENSORS FOR SMART ENERGY MANAGEMENT
In the AIM architecture, the wireless sensor network (WSN) provides the basic tools for gathering information on user behavior and his interaction with home appliances. Moreover, the WSN provides measurements of some physical parameters like temperature and light that can be used by the system to perform some automatic adjustment of the energy management system. For this purpose we implemented a hierarchical hybrid network architecture called MobiWSN [4]. This architecture is composed by heterogeneous islands of sensor nodes with each of them created using a tree network topology. Each island is managed by a Gateway and is able to communicate with it using a stateless protocol we called *Information Exchange Protocol* (IEP). The MobiWSN Gateways are interconnected using a mesh configuration to ensure reliability and resilience to failure, and can communicate with an additional node, called Manager, that is in charge of managing network creation and reconfiguration. The MobiWSN architecture, besides providing measurements of physical parameters like temperature and light, is also able to detect user presence in each room of the house. This functionality has been achieved defining a specific protocol that we called *infrared-based Presence Detection System* (i-PeDS), based on *Passive InfraRed* (PIR) sensors.

3. USER PROFILING
The basic function of the user profile is the characterization of users behavior so that some settings of the energy management system can be made automatically. For this reason we used the MobiWSN architecture for monitoring environmental parameters, such as user presence, temperature and light. This information is aggregated and processed in order to create three different types of profile (user presence profile, temperature profile and light profile) that represent users habits. In the user presence profiling (the same can be said of temperature and light profiling) the sensor network collects 24 hour information (here called *"daily profile"*) about users presence/absence in each room of the house in a given monitoring period (i.e. week, month). At the end of the monitoring time the cross-correlation between each couple of 24 hour data presence is computed for each room of the house in order to cluster similar daily profiles. In particular, daily profiles *y(t)* and *x(t)* are said similar if:

$$r(x, y) > \frac{1 - A}{2}[r(x, x) + r(y, y)]$$

Where $r(x, y)$ is the mean value of the cross-correlation between signals $x(t)$ and $y(t)$ calculated with an accepted delay of $\pm B$ (in minutes), A and B are constants (respectively equal to 0.12 and 10 in our numerical results).

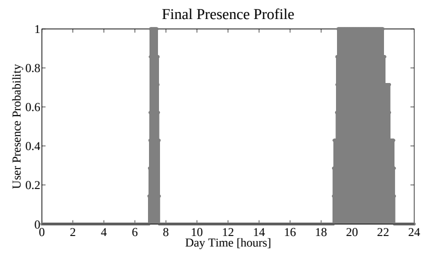

Figure 1: Example of final presence profile.

For each cluster the average of the daily profiles identifies a final presence profile that provides the 24 hour probability distribution of the user presence in the room the cluster is associated with (Figure 1). At the end of calculation a matrix is generated where each room is associated with a column that represents the sequence of presence profiles identified in the monitoring period. Each matrix column is statistically elaborated in order to predict the presence profile in a given day, for each room, on the basis of the observed profiles in the past days. For room i, for example, the prediction algorithm performs:

1) for each presence profile j in the selected column, the probability that it occurs after the sequence of profiles of the past M days in room i (with $M = 1$) is calculated;
2) if a profile j exists with such a probability higher than a threshold (experimentally set to 0.75), the algorithm stops and j is the predicted profile; otherwise M is increased by 1 and the algorithm goes back to step 1.

The prediction algorithm provides presence, temperature and light profiles for each day of the year. Obviously users habits are only partially predictable. For this reason the system has to be able to detect exceptions in the user behavior and to adjust missed predictions. For this purpose we implemented a specific algorithm, called *Updating Algorithm*, that uses real time data provided by the sensor network to dynamically update the predicted profiles during the day.

4. NUMERICAL RESULTS

As previously mentioned, we implemented a prototype version of the proposed sensor network architecture for energy management. However, to evaluate the performance of the user-habits prediction algorithms we have been forced to rely on simulation mainly because of the long period of time required for testing them in a real environment. The system has been tested referring to a five room house with a simulating period of 300 days, creating a realistic sequence of daily presence, light and temperature profiles. The presence prediction algorithm has been simulated in three user behavior exceptions cases: exceptions spike (there are 20 isolated exceptions in the users behavior), exceptions burst (there are 4 sequences of 4 contiguous exceptions) and behavior variation (user changes his behavior two times during the year). The results of the 300 days simulation are presented in Table 1.

	Room				
	1	**2**	**3**	**4**	**5**
Exceptions Spike	88.00%	90.33%	87.67%	88.67%	87.00%
Exceptions Burst	94.00%	92.00%	93.67%	91.67%	93.33%
Behavior Variation	90.00%	91.00%	90.00%	91.67%	90.67%

Table 1: Percentage of correctly predicted profiles for each room of the house.

The presence, temperature and light profiles can be used to optimize the using time of home appliances and to minimize the home energy consumption. In Figure 2 and 3 we present an example of the automatic temperature management benefits. The management system allows some energy savings turning off the cooling system of the rooms that are not required to be air conditioned because the user will not enter those rooms with high probably and turning it off in the whole house if the user is not present and probably will not return for a long time. In contrast, in the "classical scenario" the cooling system is supposed to be On in all rooms and to be preprogrammed from the user to approximately follow his daily/weekly schedules. In the simulation performed, the home temperature management has reduced the working time of the cooling system by nearly 28 percent.

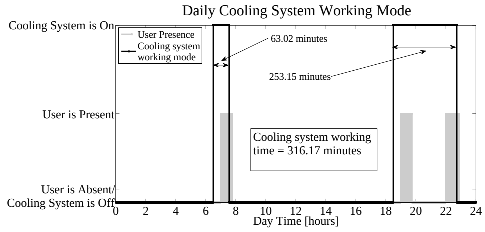

Figure 2: Room 3 daily cooling system working mode without home automation

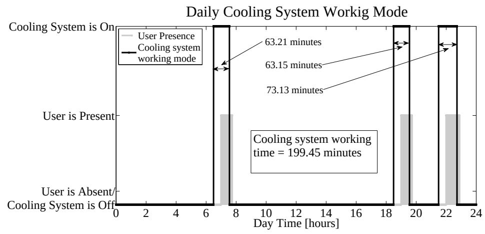

Figure 3: Room 3 daily cooling system working mode with home automation

5. CONCLUSION

In this paper we presented a home energy management system under development within the European project AIM. We proposed an heterogeneous hierarchical sensor network architecture to gather physical parameters and to monitor user behavior. Data collected by the sensors are used to create user profiles. Based on user profiles and real-time information provided by the system, we can predict user behavior and optimize the energy consumption automatically controlling home appliances. We proposed a new approach to implement a self adaptive prediction algorithms to set several parameters (light intensity, temperature, etc.) according to user estimated preferences. The presented solution is simpler than other profiling systems, mentioned in Section 1, which rely on complex learning techniques: just replicating a previously observed set up that satisfied the user in a similar context provides good results. We implemented a prototype version of the proposed sensor network architecture and simulated our prediction algorithms over long time periods showing their effectiveness in estimating users behaviors. Moreover, a prototype of the whole AIM system has been realized with the collaboration of the other partners of the project and it is actually under test in different real use case scenarios.

6. REFERENCES

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