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Centralized Peak Consumption Smoothing Revisited for Habitat Energy Scheduling

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***Abstract*—**Currently, electricity suppliers must predict the consumption of their customers in order to deduce the power they need to produce. It is then important in a first step to optimize household consumptions to obtain more constant curves by limiting peaks in energy consumption. Here centralized real time scheduling is proposed to manage the equipments starting in parallel. The aim is not to exceed a certain limit while optimizing the power consumption across a habitat. The Raspberry Pi is used as a box; this scheduler interacts with the various sensors in 6LoWPAN. At the scale of a single dwelling, household consumption decreases, particularly at times corresponding to the peaks. However, it would be wiser to consider the use of a residential complex so that the result would be more significant. So the ceiling would no longer be fixed. The scheduling would be done on two scales, on the one hand per dwelling, and secondly, at the level of a residential complex.

***Keywords*—**Smart grid, Energy box, Scheduling, Gang Model, Energy consumption, Energy management system, and Wireless Sensor Network.

I. INTRODUCTION

PRESENT project is concerning optimal management of habitat energy consumption. Observation of consumption shows the existence of sharp peaks very localized in time leading to important losses if production is as today delivered from large, centralized units with very slow response time. Two ways can be invoked to reduce such losses, corresponding to better management of consumption at local scale to smooth it out, and to organize better energy mix for fitting more closely the demand on larger scale. For the first, this is still under debate to determine the parameter domain where there is advantage for distributed organization over centralized one to run more efficiently the partition of limited amount of resources amongst a certain number of consumers.

Classical approach to resource access problem is a centralized one where a unique intelligent agent [1], [2] controls fluxes from production system. This leads to choice of algorithm determining best possible combination. Producer will then evaluate all combinations before choosing best one. Such problem belongs to NP class and induces very limiting combinatorial explosion. Usually this is avoided by heuristic use. Even if as a consequence optimal solution is not reached, the problem can be solved within reasonable time. Centralized approach is simple and efficient, but it requires the knowledge of system state. Practically, this is not always the case, and system will have to internally approximate its structure.

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In distributed approach [3]-[7] on the other hand, several intelligent agents are controlling fluxes. They are situated at local level, i.e. they are consumers sharing the flux coming from producer. Distributed intelligent algorithms mainly fall into two categories:

- Cognitive approach, with very intelligent entities and weak interactions. Best results would correspond to complete split of initial interactive system into a set independent “components” representing at local level all system possible dynamics [8]-[9].
- Reactive approach with weakly intelligent entities and strong interactions (for modeling social phenomena such as decision making in ant colony [10]-[12]).

Distributed approach imposes a Multi-Agent System (MAS) [13], [14], developed through specific tools [15]. Key point in distributed approach is communication. As agents are completely independent a strict communication protocol should be set up for their interaction. MAS are often more realistic with large number of interacting elements. They are by nature more flexible on system global structure such as population variation, as individual agent existence is not directly depending on it. But development of distributed approach is often very complex and results are not always as significant as with centralized approach. Both previous (and opposite) approaches have each shown their limits. They both have in common to be ‘’universal’’ in that they use only a global (macroscopic) vision and do not account for system structure and its specific properties. To proceed further, it is thus interesting to analyze it. For the case of relatively few consumers, advantage of distributed organization is not so evident by the information flux exchange constraints it implies.

Here, taking advantage of more accurate description of system components, it will be shown that with centralized approach an optimum distribution can be set up based on observation of consumption peaks. The idea is to have all housing equipments communicate with a centralized scheduler which manages power distribution within the habitat by rolling over equipments consumption to least expensive time period so that they can all satisfy their duty within a prescribed time interval and with prescribed maximum energy consumption. From a comprehensive state of the art on EMS (Energy Management System) [16], [17], it has been observed that all boxes representing system components are using the same techniques: electrical effacement, energy consumption analysis, heating and lighting control and alerts in case of overconsumption. The real time scheduling, an approach different from the field of computers, has been adopted. The scheduler will place the equipments in a certain order to avoid the two energy peak consumptions during a day which are really expensive for electricity suppliers. This scheduling will make overall habitat consumption as smooth as possible with a priority to user comfort.

II. Context

The different equipments of typical habitat will be ordered as follows. Equipments are called random if their starting time cannot be predicted, and cannot be displaced. Typically, one cannot move the start of a television to meet user comfort. Programmable equipments on the other hand are equipments the start of which can be moved in time without disrupting user comfort (e.g. washing machine).

Indeed, using a model of scheduling processors described in Part A below, a typical day can be split in four periods: the occupation of habitat in the morning, the vacancy period during the day, the period of occupation in the evening, and the night.

The issue of present paper is the scheduling of programmable equipments during vacancy period and at night. The idea is that the user can activate the programmable equipments during periods of occupation, but they will be switched on only during the vacancy period, or during the night.

A. The Gang Model

The paper relies on the Gang Model [18], [19] which describes different processors scheduling algorithm. Some properties of this model are used for incorporating it into the energy field. It is based on two algorithms, "in the dark" and "clairvoyant", from which the semi-clairvoyant algorithm is defined as a basis of the model.

1. The "In The Dark" Algorithm

If the number of processors available is sufficient to complete a task before its deadline, the task is executed. The algorithm does not take into account the tasks at runtime, which may be interrupted due to processor assignment to a new task. The algorithm does not plan the tasks.

2. The "Clairvoyant" Algorithm

This algorithm provides a complete profile of tasks to be performed and assigns to each of them the adequate number of processors. Profile sets cannot be changed, and a new job outside the profile will run long after application.

The first algorithm does not provide enough future operations or their impact on the tasks at runtime. The second, in contrast, provides too much and leaves no room for performing a task that does not belong to pre-established profile. So the chosen intermediate algorithm will be called "semi-clairvoyant".

3. The "Semi-Clairvoyant" Algorithm

It approximates the clairvoyant algorithm scheduling tasks but for running only on a defined period. This helps promote both tasks at runtime, and the tasks to be performed. Present paper uses some transposition of this model to energy model in the sense that the number of allocated processors corresponds to habitat power limit. Gang Model which is semi-clairvoyant algorithm is used in the same way because the day is split into four periods during which each equipment will be programmed.

Two constraints are considered, a power constraint and a time constraint. Recall that the problem only focuses on programmable equipment. Let:

$E = \{e_1, e_2,\dots, e_n\}$ as the set of tasks to be performed during a period *T*. In other words, *T* is the period over which the scheduling of *n* tasks must be performed.

p_i the average power for task e_i.

$E_c = \{f_1, f_2,\dots, f_n\}$ the set of consumption functions associated with all tasks of E and max (f_i) the maximum consumption function of task *i*.

III. System Constraints and Algorithm

A. Power Constraint

Consider a power limit not to exceed P_{max}. A set of tasks $E = \{e_1, e_2,\dots, e_n\}$ is defined. A task e_i corresponds to the execution of an action by equipment i for a period t_i beginning at time t_d and ending at time t_f. Let the nominal power of all programmable equipments P_i as $P_{tot} = \Sigma P_i$, P_{tot} is the sum of nominal powers.

B. Time Constraint

Equipment activation will be carried out according to a second constraint, the time *T*, which it is also interesting to optimize as well as the power limit described above. This time *T* is the vacancy period during the day, or the period of sleep at night. It corresponds to user periods of inactivity where only programmable equipment can be activated. *T* is the input variable to be provided by the user when giving preferences. The algorithm will be the same for vacancy period during the day, and for night.

C. Scheduling Algorithm

There are two trivial cases. The first one is when for *i* scheduled tasks, the following inequality holds:

$$\sum t_i < T. \quad (1)$$

The second trivial case is:

$$P_{tot} = \sum p_i < P_{max}. \quad (2)$$

If the *i* scheduled tasks satisfy both (1) and (2), they will be ordered one after the other rather than running simultaneously. If (1) is satisfied and (2) is not, the tasks are performed one after the other. If (2) is satisfied and (1) is not, the equipment are started simultaneously.

The case where both inequalities are not satisfied is not trivial. Then *T* is the input variable and one seeks to minimize P. In this case the scheduling algorithm is applied.

Algorithm Principle:

To explain the algorithm, equipments consumption is modeled by rectangular blocks. *T* is the time during which the equipment must be running (user-defined). T_{tot} is the total time of all equipments when they are placed one after the other. One defines $T_d = T_{tot} - T$ which must be less than or equal to *0* in order to satisfy the time constraint. A diagram is constructed with blocks representing each equipment task and the different variables: T_{tot}, T_d, e_i, ..,placed and reorganized according to three steps, see Fig. 1.

Step 1. Equipments are sorted in ascending powers in the list: $E=\{e_1, e_2,...e_n\}$

Step 2. In the list of all the tasks, the two equipments of lower power are selected and their two representing blocks are superposed as displayed on Fig. 1:

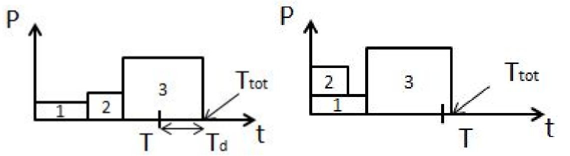


Fig. 1 To meet time constraint *t*, the two blocks of lower powers stack on top of one another (block 2 on top of block 1)

The second task is added to the first at the moment when the power is minimal. Both tasks are added as a new task, denoted $e_1 + e_2$ and the new list is then formed $\{e_1 + e_2, e_3, \ldots, e_n\}$.

Step 3. T_d is calculated. If T_d is greater than 0 return to step 2.

IV. Algorithm Implementation

In this section, consumer equipments are no longer considered as rectangular blocks but as functions. The algorithm therefore combines all the tasks $\{e_1, ..., e_n\}$ as a set of consumption functions $\{f_1, f_2, \ldots, f_n\}$.

Step 1. The set of functions f_i are sorted in ascending consumption order $E_c = \{f_1, f_2, ..., f_n\}$. Subsequently, E_c will be considered as a list of functions each defined on a precise interval which may differ depending on the tasks e_i. Denote $E_c(i)$ the *i*–th element of this list and $t(E_c(i))$ the duration of task e*i* corresponding to this function.

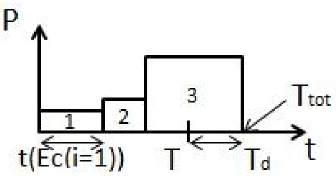


Fig. 2 Equipment consumption as time functions rather than blocks (with$E_c(i)$)

Step 2. While (t_d>0) //Until $T_d = T_{tot} - T$is greater than*0*onegoes around an extra loop

{
i=0 ;
// The two functions corresponding to smallest power are added by operator $F_{add}(E_c(i),E_c(i+1))$explicated below
//One checks if the space vacated by previous addition of two functions is sufficient to meet the time constraint. If so, the loop is exited, otherwise another iteration loop is performed.
$T_d = T_{tot} - T$;
i++ ;
}

The add function F:

This function takes two functions of $E_c$list and adds them in a very specific interval. To determine the interval of addition, one first finds the minimum of first function by solving:

$$d(E_c(i))/dt = 0 \tag{3}$$

The abscissa t_l of the minimum will be the left terminal of the interval, denoted $t_l = \min(E_c(i))$. The right terminal $t_r$of the interval will be determined by the following expression:

$$t_r = \max(t(E_c(i+1)) + \min(E_c(i)), t(E_c(i)) \tag{4}$$

Function $F_{add}(E_c(i), E_c(i+1))$ will add the two functions on the interval :

$$[t_l,t_r] = [\min(E_c(i)) ; \max(t(E_c(i+1))+\min(E_c(i)),t(E_c(i))] \tag{5}$$

As constructed, present algorithm finally minimizes P while respecting the time constraint *T*.

V. Tests and Results

A. Scheduling Tests

To test the proposed solution, two different modes have been considered. The first mode is automatic scenario. This scenario provides the consumption of a habitat following French consumption average [20]. For each equipment, the following parameters {run time, start time, end time frequency of use of the equipment in a day} have been fixed. They are implemented in the scheduler which then sets the curve of energy consumption within the home. Each equipment simulated by automatic scenario will ask if the scheduler can run or not according to scheduling algorithm.

The second mode is the manual scenario. This scenario simulates real-time scheduling algorithm. Sensors Kit Raven [21] is used to simulate the electrical habitat. Thus, a simple press of the button will simulate the sensor's user switching equipment. This test mode allows test scheduling algorithm in real conditions.

B. Results

To smooth out electricity consumption curve with proposed scheduling for habitat equipments, they are clustered into three categories:

- The random ones with non regular and predicable activation
- The programmable ones which follow a predetermined sequence which cannot be stopped unless one should restart the duty cycle from the beginning, such as a washing machine, a dryer or a dish washer. These equipments are used in a relatively regular manner

– The constant equipments utilizing periodically energy for some time intervals, such as VMC and refrigerator.

On the other hand, heating can be used in two different ways, one for heating the whole house and the other one for hot water tank (with adiabatic vessel allowing heating long before utilization). So house heating can be started typically 30mn before inhabitant arrival, whereas hot water tank can be activated much longer before.

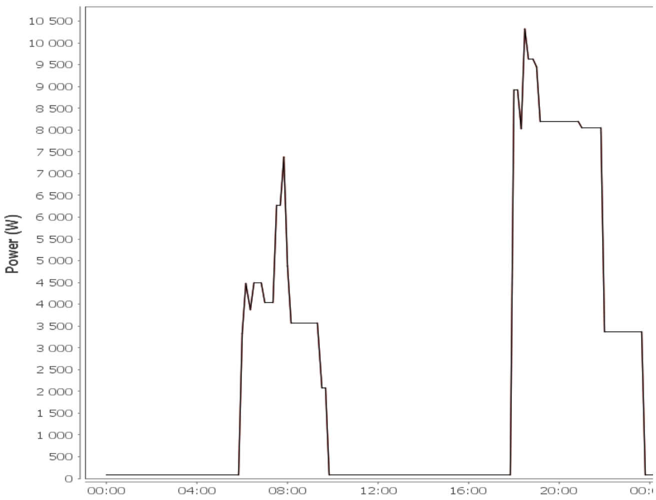
The sequence of firing up the equipments (the blocks on Figs. 1 and 2) has been defined depending on allowable time interval. If it is large, one will try to put the blocks one after the other, knowing that the scheduler puts the larger blocks first and follows the firing order of the tasks to give the user the largest power in case of earlier return at home. If the time interval is small, the scheduler puts smaller blocks on top of large ones. If their addition exceeds the power limit, their firing is slide to a later time period.

In first automatic mode 5 scenarios are included for validation. Without scheduling the system is driven by user desire. Two main periods are distinguished in the year, summer and winter, where the user can be either at home or at work.

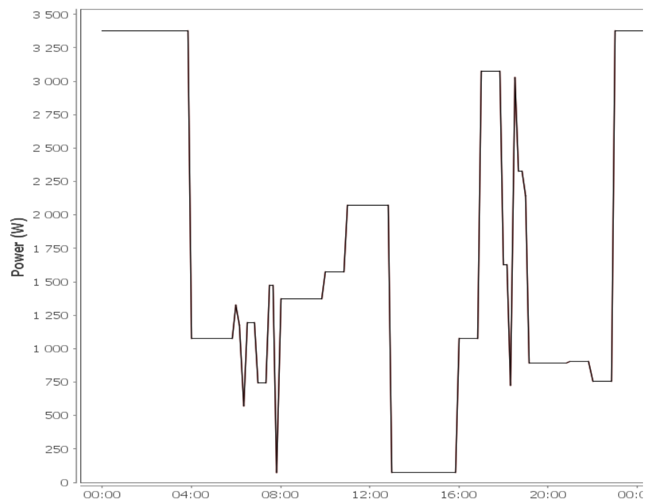
In manual second mode user behavior can be simulated by inserting different time intervals for equipments activation during the week-end and during week working days. Even if obtained curves may not represent perfect reality, it is already possible to verify their interaction with proposed algorithm.

Interesting results are found when comparing consumption curves for different scenarios with a model habitat of 100 m^2 with 4 inhabitants, see Appendix for parameter description. Three basic scenarios have been considered where equipments have been fired at the same time for ease of comparison: scenario 1 without scheduling for reference, scenario 2 with scheduling during winter period (i.e. with home heating) and scenario 3 during summer period (i.e. without home heating). Results are displayed on Figs. 3 (a)-(c), respectively.

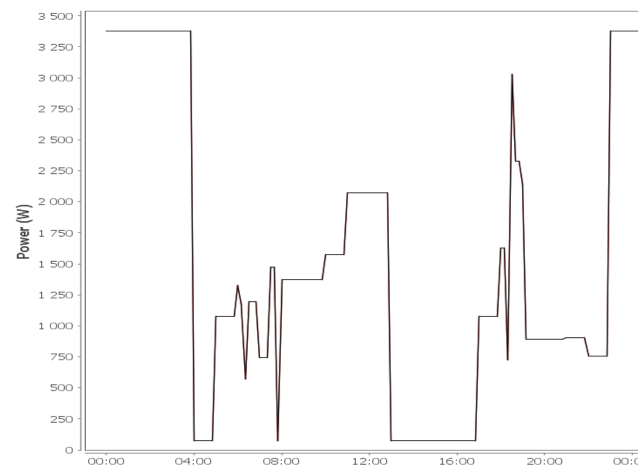
First observation on Fig. 3 (a) is that consumption takes only place when inhabitants are at home and not asleep, and exhibits two important peaks at 7400W in the morning with a pedestal at 4200W and at 10350W in the evening with a pedestal at 8000W. Such uncontrolled consumption creates high difficulty for distribution network and producers to be satisfied. With scheduling, it is observed that in scenarios 2 and 3 see Figs. 3 (b), (c), some equipments (washing machine, drier, dish washer, electrical vehicle and heat accumulators) are shifted to inoccupation periods. There is little difference between the corresponding consumption curves which just stays in the time intervals 4:00am-6:00am and 16:00pm-18:30pm and, in particular, peak values are completely erased and dramatically reduced to 3400W typically to 1/3 of non scheduled value. Already for this simple case does scheduling show very effective and more manageable consumption reduction which could not be easily improved due to high consumption levels of some equipments (electrical vehicle, heat accumulator, drier).



(a)



(b)



(c)

Fig. 3 (a) One day consumption with scenario 1, (b) one day consumption with scenario 2, (c) one day consumption with scenario 3

VI. Conclusion and Future Work

Present study has been devoted to reduction of peaks consumption usually occurring in habitat without application of any specific rule, and which are responsible of large power waste when considering a whole country. Many methods have been proposed so far with great interest recently for distributed ones which have been shown to overcome the inherent difficulty of centralized more classical methods to generate NP-complex problems because of combinatorial explosion produced by analysis of full system network. However there remains to determine the critical number N_{crit} of system elements above which this (asymptotic) property is effective and makes the switch to distributed control methods inevitable. Along this line a centralized method using a simple scheduling has been proposed and applied to a representative habitat. The obtained results when considering different possible inhabitant behaviors and different situations are very clearly showing that classical approach is still in order in this case with a first cut reduction of peak consumption by a factor of three.

Despite the fancy appeal of smart and/or intelligent distributed approaches, the problem of peak consumption reduction can be efficiently handled with very inexpensive and robust method discussed here. The very reason is in the great dispersion of individual power consumption of the various consuming elements in a habitat which, apart a few large ones, includes many low consumption elements. It is not worth it to equip these last ones with high quality communication modules for exchanging further information. This is almost useless here as it has already been mentioned from observation of the results that the low obtained peak is almost at the level of highest individual consumption. A consequence is that the number N_{crit} is not the only parameter fixing the switch to distributed methods which are not really making a difference when as in present case there are many small consumption elements. Present results suggest to keep centralized method at basic habitat level and to use distributed ones at higher cluster level of a certain number of apartments. Further comparison between centralized and distributed methods will be discussed elsewhere.

In present study only power reduction satisfying time constraint has been considered. A more realistic approach would imply to also account for energy cost as a function of time slot, i.e. to introduce electricity cost at equipments launch time. Corresponding program will have to work on many tests at the approach to cost switching time to determine lowest expense partition under the constraint of fixed running time *T*. In a second loop variation on *T* within natural fixed limits will determine best optimal scheduled solution. Extension of energy task scheduling to higher level cluster of several habitats is interesting to determine the relevance of classical centralized approach applied to such cluster and in particular to evaluate the number of elements in the cluster above which distributed approach is more appropriate. Such problem will be discussed elsewhere.

Appendix

100 m^2habitat is considered with four inhabitants. Tests are performed during a working day where inhabitants are at home and active from 6:00am to 8:00am and from 18:00pm to 23:00pm, and are sleeping from 23:00pm to 6:00am.

The following table displays power consumption of habitat electrical equipments and their working cycles used in the different scenarios.

TABLE I
Habitat Parameters

Power watts	Equipment	Working Cycle
170	TV	6:30-7:30 ; 19:00-23:00
*1310**	Lightings	6:00-8:00 ; 18:00-23:00
1500	Cooker	18:30-19:00
1250	Microwave Hoven	19:00-19:10
900	Iron	7:30-7:50 ; 18:00-18:20
700	Vacuum Cleaner	18:30-18:40
600	Toaster	6:10-6:20
100	Pumping Hood	18:30-19:00
450	Hair Drier	6:30-7:00
150	Personal Computer	18:00-21:00
750	Coffee Machine	6:00-6:10
10	DVD Reader	21:00-23:00
34	VMC	24/24
41	Refrigerator	24/24
1300	Washing Machine	6:10-8:10 +
2000	Drier	7:50-9:50 +
1500	Dish Washer	7:30-9:30 +
3300	Electrical Vehicle	18:00-2:00 °
1000	Heater (no scheduling)	6:00-8:00 ; 18:00-23:00
3000	Heat Accumulator (only with scheduling)	4:00-5:00 ; 16:00-17:00
1000	Heater Sanitary Water	6:00-6 :30 ; 18:00-18 :30(scénario 1) 5:00-5 :30 ; 17:00-17 :30 (scénario 2)

*13.1W/m^2 ; +Shifted when unoccupied habitat with scheduling
° Shifted to night time with scheduling

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