Intelligent Scheduling of Smart Appliances in Energy Efficient Buildings: A Practical Approach

Nilotpal Chakraborty, Arijit Mondal, Samrat Mondal
Department of Computer Science and Engineering,
Indian Institute of Technology Patna, Bihar, India.
Email: {nilotpal.pcs14, arijit, samrat}@iitp.ac.in

***Abstract*—In this work, we propose a scheduling algorithm, named *mixed*-MinPeak, to schedule deferrable appliances that can be of both preemptive and non-preemptive types, together in the presence of non-deferrable appliances. The performance of the proposed algorithm has been evaluated on practical power consumption data, along with a comparative analysis with existing algorithms, the results of which prove the capability of the proposed algorithm in producing better solutions.**

***Index Terms*—Preemptive, non-preemptive, scheduling, peak load reduction, direct load control, demand response.**

I. Introduction

An integral aspect of the next generation electrical grid, known as the smart grid, is demand response (DR) that provides the flexibility in controlling the electrical appliances and minimizing electricity costs by utilizing the energy generation resources more efficiently [1]. DR introduces various load scheduling and energy management solutions, such as direct load control or dynamic pricing techniques, using which it tries to reduce peak load demand better.

Existing literature on DR have classified residential and industrial loads into non-deferrable (whose power consumption cannot be controlled) and deferrable loads (operations of which can be controlled) [2]. However, a majority of the state-of-the-art algorithms consider the controllable or deferrable appliances to be of non-preemptive type only, ignoring the fact that in real life, appliances can be preempted as well depending on its operation and system requirements. For example, let us consider that a washing machine needs to be operated for 3 hours within 5 PM to 11 PM, which overlaps with the peak-hours from 6 PM till 9 PM. If only non-preemptive scheduling is considered, the operation of the washing machine is bound to overlap with the peak hours, however, allowing preemptive in its operation (by running from 5 PM till 6 PM and then from 9 PM till 11 PM), we can avoid the peak hours. This will reduce peak load demand and consumers' electricity cost.

In this paper, we study and analyze the optimization problem of peak load reduction under such practical circumstances, where deferrable appliances can be operated in both preemptive and non-preemptive mode, and propose a new scheduling approach, based on the MinPeak algorithm. The performance of the proposed approach has been experimentally proved to be superior to some of the existing approaches.

II. System Modelling

Let us consider a total of $\mathtt{m}$ appliances, out of which $\mathtt{d}$ are deferrable and the rest are non-deferrable, which are to be scheduled within an overall time horizon of $\mathcal{T} = [0, \beta]$. Among the $\mathtt{d}$ deferrable appliances, let $\mathtt{p}$ are preemptive and $\mathtt{np}$ are non-preemptive. Let us denote the set of non-deferrable appliances as $\mathtt{A}_n$, preemptive appliances as $\mathtt{A}_p$, and non-preemptive appliances as $\mathtt{A}_{np}$.

A status information is maintained for the appliances $U_i, \forall i \in [1, \mathtt{m}]$, which is represented as a tuple $\mathcal{S}_i = \langle \mathcal{E}_i, \mathcal{W}_i, s_i^t, r_i^t \rangle$, where $\mathcal{E}_i$ represents execution time, $\mathcal{W}_i$ represents power consumption, s_i^t is a binary variable representing the switching state of U_i at time instance $t \in \mathcal{T}$ (0 if switched OFF, 1 if switched ON), r_i^t is the remaining time for U_i at t. The execution of appliances is constrained to be finished within the total time horizon, which can be stated as:

$$\sum_{t \in \mathcal{T}} s_i^t = \mathcal{E}_i, \forall i \in [1, \mathtt{m}] \tag{1}$$

For non-preemptive appliances we have,

$$\forall i \in \mathtt{A}_{np}, s_i^t = \begin{cases} 1, \text{ if } \mathbf{S}_i \leq t \leq \mathbf{F}_i \\ 0, \text{ otherwise} \end{cases} \tag{2}$$

where $\mathbf{S}_i$ and $\mathbf{F}_i$ are the actual starting time and overall finishing time of executing U_i. On the other hand, the deferrable appliances that can be preempted as per the requirements. Let $\mathbf{S}_i^j$ and $\mathbf{F}_i^j$ to be the start time and the finishing time of the j^{th} operating instance for appliance $U_i, \forall i \in [1, \mathtt{p}]$, with the assumption that $\mathbf{S}_i = \mathbf{S}_i^1$ and $\mathbf{F}_i = \mathbf{F}_i^k$, where $\mathbf{S}_i^1$ is the starting time of the 1^{st} instance and $\mathbf{F}_i^k$ is the finishing time of the last (k^{th}) instance. Then, the execution of preemptive appliances must satisfy the following constraints:

$$\mathbf{S}_i^j < \mathbf{F}_i^j < \mathbf{S}_i^{j+1}, \forall i \in \mathtt{A}_d \tag{3}$$

$$\forall i \in \mathtt{A}_d, s_i^t = \begin{cases} 1, \text{ if } \mathbf{S}_i^j \leq t \leq \mathbf{F}_i^j, \forall j \in [1, k] \\ 0, \text{ otherwise} \end{cases} \tag{4}$$

$$\sum_{t=\mathbf{S}_i^1}^{\mathbf{F}_i^k} s_i^t = \mathcal{E}_i, \forall i \in \mathtt{A}_d \tag{5}$$

Satisfying all the aforementioned constraints, our objective can be expressed as:

$$Minimize : W_{tot}^t = \sum_{i \in [1, \mathtt{m}]} W_i \times s_i^t, \forall t \in \mathcal{T} \tag{6}$$

III. Proposed Scheduling Algorithm

In this section, we present and discuss a new algorithm that is capable of efficiently scheduling both preemptive and non-preemptive appliances along with the non-deferrable ones, named *mixed*-MinPeak, which is based on the MinPeak algorithm [3]. Like MinPeak, *mixed*-MinPeak also starts with analyzing the feasibility of the input specifications. It maintains a load array ($\mathcal{L}$) and an array of lists ($\mathcal{G}$) of sizes

2380-6923/19/$31.00 ©2019 IEEE
DOI 10.1109/VLSID.2019.00114

equal to the scheduling horizon ($\mathcal{T}$) to contain the total power consumption and the set of appliances scheduled at different time instants respectively. To begin with, the *mixed*-MinPeak algorithm classifies the set of appliances based on their types, i.e., non-deferrable, preemptive, or non-preemptive. Since non-deferrable appliances do not offer any flexibility, they have the highest priority among the various types of appliances and therefore, the proposed algorithm schedules them first. Once the non-deferrable appliances are scheduled, we can proceed towards scheduling the deferrable appliances. However, among the preemptive and non-preemptive appliances, we consider prioritizing the scheduling of non-preemptive appliances more to the preemptive appliances, since the preemptive appliances are less rigid in their operations as compared to the non-preemptive ones.

For each of the deferrable appliances, we distinguish them either as preemptive or non-preemptive and proceed with scheduling the non-preemptive set first, in the same way as that of the original MinPeak algorithm. Mathematically, this can be obtained by computing the minimum load sub-array (P_i) for the non-preemptive deferrable appliance i within the load array $\mathcal{L}$ by computing $P_i(a) = \min_a(\sum_{t=a}^{a+\mathbf{R}^u} \mathcal{L}[t]), \forall a \in \mathcal{T}$. If multiple such $P_i(a)$ are obtained, the one with the least peak is finally selected for i. Ties are broken arbitrarily in case the peak values are same for multiple $P_i(a)$. The preemptive appliances, being the least prioritized set, are scheduled after all the non-preemptive appliances are placed successfully. For such appliances, the *mixed*-MinPeak algorithm schedules one instance of the desired execution time at a time for a particular appliance. Finally, when all the appliances are successfully scheduled, the algorithm returns $\max \mathcal{L}$ as the peak value of the schedule as the output.

IV. Results and Discussions

In this section, we evaluate and analyze the performance of *mixed*-MinPeak algorithm considering the decreasing height (DH) variant of *mixed*-MinPeak, call it *mixed*-MinPeak-DH using real-life power consumption data and have compared it with that of an existing state-of-the-art scheduling algorithm. In particular, a comparison has been carried out with the *Bottom Left Decreasing Height* (BLDH) as used in [4]. The input data set is shown in Table I.

Table I: Appliance specifications

Deferrable Appliances	Wattage (kW)	Non-deferrable Appliances	Wattage (kW)
Cloths dryer	$[2.7-3.0]$	Ceiling fan	$[0.03-0.04]$
Dish washer	$[1.2-1.5]$	Computers	$[0.25-0.08]$
Washing machine	$[0.5-1.5]$	Electric frying pan	$[1.0-1.5]$
Vacuum cleaner	$[1.0-3.0]$	Heating load	$[1.0-3.0]$
Toaster	$[0.8-1.5]$	Electric kettle	$[1.5-2.5]$
Water heater	$[1.5-5.0]$	Coffee maker	$[0.75-1.2]$
PHEV	$[5.0-9.9]$	Lighting bulb	$[0.4-0.1]$

Table II: Comparative performance analysis of *mixed*-MinPeak-DH with BLDH algorithm for 1000 appliances.

% of deferrable appliances	% of preemptive appliances	Peak obtained by: mixed-MinPeak-DH	BLDH
25	25	436.33	492.28
	50	431.62	488.49
	75	427.51	483.26
	100	421.34	478.44
50	25	418.91	458.18
	50	416.33	452.70
	75	407.72	449.09
	100	402.89	442.36
75	25	394.78	436.18
	50	390.60	431.18
	75	383.55	428.97
	100	380.46	426.74
100	25	373.91	417.90
	50	367.78	412.19
	75	365.37	405.64
	100	361.94	405.64

We have generated a total of 500 test cases from the given set of appliances in Table I, to schedule 1000 appliances. Each of the test cases contains non-deferrable, preemptive, and non-preemptive appliances. The execution time for each of the appliances have been varied within $3-8$ hours randomly and the overall scheduling horizon is considered to be 24 hours for all the test cases. Table II shows the performance of *mixed*-MinPeak-DH under the practical condition. The two primary observations from the table are 1) peak load demand decreases with the increase in % of deferrable loads, and 2) as we decrease the % of non-preemptive appliances, the resulting peak load demand gets reduced. Overall, shifting from 25% deferrable to 100% deferrable yielded a 16.92% peak load reduction, whereas increasing the % of preemptive appliances from 25% to 100% resulted in a peak load reduction of 3.8% for the *mixed*-MinPeak-DH algorithm. Table II also shows a comparison of the peak obtained by *mixed*-MinPeak-DH and existing algorithms with *BLDH* algorithm. As can be observed from the table, *mixed*-MinPeak-DH has performed significantly better than the *BLDH* algorithm, resulting in 12.08% lesser peak. This speaks of the capability and effectiveness of the proposed algorithm in a real-life scenario. Moreover, all the results for practical dataset have been obtained without any significant computational overhead.

V. Conclusion and Future Work

We proposed an intelligent variant of MinPeak algorithm, named *mixed*-MinPeak, and discussed its performance and efficiency. The results obtained show that the proposed algorithm is highly efficient and performs better in comparison to the existing approaches. As part of our future work, we are looking forward to obtaining an online variant of the proposed algorithm.

References

[1] P. Palensky and D. Dietrich, "Demand Side Management: Demand Response, Intelligent Energy Systems, and Smart Loads," in IEEE Trans. on Industrial Informatics, vol. 7, no. 3, pp. 381-388, Aug. 2011.

[2] S. L. Arun and M. P. Selvan, "Intelligent Residential Energy Management System for Dynamic Demand Response in Smart Buildings," in IEEE Systems Journal, vol. 12, no. 2, pp. 1329-1340, June 2018.

[3] N. Chakraborty, A. Mondal and S. Mondal, "Efficient Scheduling of Nonpreemptive Appliances for Peak Load Optimization in Smart Grid," in IEEE Transactions on Industrial Informatics, vol. 14, no. 8, pp. 3447-3458, Aug. 2018.

[4] A. Ranjan, P. Khargonekar and S. Sahni, "Smart grid power scheduling via bottom left decreasing height packing," 2016 IEEE Symposium on Computers and Communication (ISCC), Messina, 2016, pp. 1128-1133.