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Harmony Pigeon Inspired Optimization for Appliance Scheduling in Smart Grid

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***Abstract*—Since the development of Smart Grid (SG), Home Energy Management (HEM) systems are emerged widely into it and consumers have an opportunity to schedule their smart appliances efficiently in smart homes. In this research, meta-heuristic techniques Harmony Search Algorithm (HSA), Pigeon Inspired Optimization (PIO) and our proposed Harmony Pigeon Inspired Optimization (HPIO) are adopted to efficiently schedule smart appliances in smart home. The aim of using the above proposed techniques is to reduce Electricity Cost (EC) and Peak-to-Average Ratio (PAR). HEM is proposed to further evaluate the performance of evaluated techniques. In this work, single home and multiple homes which consist of 10 ,30 and 50 homes are considered equipped with multiple smart appliances. These appliances are divided into three sets, which are thermostatically and non-thermostatically controllable, and non-controllable appliances under Time-of-Use (ToU) pricing scheme. Simulations are carried out on these parameters and results shows that proposed technique HPIO performed better than HSA and PIO in terms of minimizing waiting time and PAR. We have considered User Comfort (UC) in terms of waiting time.**

***Keywords*—smart grid; demand response; harmony search algorithm; peak-to-average ratio; user comfort**

I. INTRODUCTION

Energy utilization demand is increasing day by day as compared to energy generation. Traditional grids are unable to meet those requirements and tackle it by the increasing energy generation problem as a peak demand. In order to achieve this problem SGs are presented. The power exchange and load shifting of systems in high penetrating in RER is focus of [1].Author adopted game theoretic approach for solving problem of power trading and load scheduling along with proposed control algorithm. Objective achieved in this study is minimizing energy cost more ever consumers can also save electricity and sell it to local users for more price than utility and consumers can buy

ACRONYMS

GA	Genetic Algorithm
BPSO	Binary Particle Swarm Optimization
PIO	Pigeon Inspired Optimization
HSA	Harmony Search Algorithm
HPIO	Harmony PIO
HMCR	Harmony Memory Consideration Rate
PA	Pitch Adjustment
LP	Linear Programming
UC	User Comfort
PH	Peak Hours
OPH	Off Peak Hours
ToU	Time of Use
RER	Renewable Energy Resources
CPP	Critical Peak Pricing
DAP	Day Ahead Pricing
RTP	Real Time Pricing
PAR	Peak to Average Ratio
LOT	Length of Operational Time
OTI	Operational Time Intervals
SM	Smart Meter
DE	Differential Evolution
EDE	Enhanced Differential Evolution
PSO	Particle Swarm Optimization
MILP	Mixed Integer Linear Programming
MKP	Multiple Knapsack Problem
TLGO	Teacher Learning Genetic Optimization
DSM	Demand Side Management
SG	Smart Grid
HM	Harmony Memory
QEC	Queuing Based Energy Consumption
HEM	Home Energy Management
REMS	Residential Energy Management System
RES	Renewable Energy Sources
EC	Electricity Cost

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EA	Evolutionary Algorithm
EMC	Energy Management Controller
EMO	Evolutionary Multi Objective Optimization

electricity from neighbor in less amount than utility. In [2], different solutions are proposed for DSM to benefit entire society that is consumers and suppliers. Two techniques P1 and P2 are taken into account however these techniques failed to protect consumers privacy furthermore, authors presented pricing based game theoretical approaches called GA1 and GA2 to fill gaps of PA1 and PA2. Author focused on storage optimization and energy consumption problem and formulated as centralized optimization problem to reduce load from average demand over a day in [3], and then author proposed distributed algorithm in which users efficiently reduces their payments to the utility while maintaining global optimum solution of centralized design.Furthermore, proposed distributed system reduced peak load of system as well. Technique for balancing load is proposed in [4], for industry, residential and commercial areas. They compare the electricity consumption of various samples through DSM without GA and DSM with GA. The performed simulation results show that the applied strategy GA-DSM achieved the objective; the decrease in electricity consumption up to 22% during PH. However, PAR and UC not discussed.

Energy management objectives in SM includes: reducing cost of electricity bill, power consumption and PAR along with RES integration, while maximizing UC. QEC management for different residential demands in SG is proposed in [5]. Achieved objective of above aforementioned technique are cost and delay reduction while authors ignored PAR and RES. In [6-7] DERs are included in optimization network to reduce voltage profile, energy losses and cost of their addition into the network. The authors of [8], enlighten load scheduling as a major problem in DSM. Furthermore, authors proposed exact heuristic algorithm for load scheduling problem under real pricing and achieved within 5% of optimal cost with proposed heuristic algorithm however, authors considered only united states as a domain for particular problem.

In [9], authors investigated short term scheduling for distributed systems along with DG units. Furthermore authors optimized two different benefit functions named DGO and DisCo in a multi objective optimization context and utilized e-constraint method for solving multi-objective optimization. Furthermore results showed that power losses and load profile are dependent on the administration method of the system. However, investment of private sector can minimize network loss, while maximizing load and voltage profile. the authors of [11], presented ToU pricing scheme based on HEMS model, with and without RES. Authors used techniques like GA, BPSO, Cuckoo and EAs to optimally consume RES energy and grid. Furthermore results showed that by using aforementioned techniques cost saving is attained in terms of high peaks and electricity bill.

Hybrid technique called hybrid TLGO to reduce cost and maximize UC is proposed in [12]. The proposed technique is tested for multiple parameters and matched their results with GA, LP and TLGO results showed that proposed technique performed well in reducing cost and user discomfort while disturbing peak power consumption and PAR. As mentioned above, increase in energy consumption demand in residential area is attracting researchers towards scheduling of appliances. In this work we considered single home and multiple homes, consists of multiple smart appliances in order to minimize PAR and electricity cost and maximizing UC. For this purpose we have evaluated meta-heuristic technique called HSA, bio-inspired PIO and our proposed HPIO.

Rest of the paper is organized as follows: Section 2, contains related work. Section 3, defines the problem statement. Section 4, describe proposed solution. section 5, presents the system model. Simulations and results are covered in section 6 and finally in section 7, paper is concluded.

II. RELATED WORK

In [1], the authors proposed load control algorithm for demand side management. In which authors reflected the delinquent of power trading and load forecast to minimize the energy compensation of users. In [2], the consolidated optimal problem P1 is proposed to minimize PAR and P2 to condense total energy consumption to reduce cost. Two distributed algorithms are proposed in [3], to decrease energy expense to the energy supplier and condense a peak load. In [4], the focal impartial is to diminish the cost, pollution secretion and solve the ambiguity problem of energy sources. In [5], authors deliberated QEC organization for diverse housing demands in SG. Controllable loads modeling is proposed in [6], appropriate for both local and straight control from a direction structure for DER optimization based on multi objective optimization algorithm.

Distributed network is changed from passive to the active structure with suitable DERs to works as a

TABLE I Related Work

Algorithm	Objectives	Achievements	Limitations
Algorithm for Governing Load [1]	Reducing Load and Power Scheduling	Scheduled Appliances of Different Types	UC and PAR Ignored
Game Theory Approach [2]	Reducing Cost and Energy Cost	Reduced PAR and Cost	Customer Privacy not Protected
Distributed Algorithm [3]	Storage and Energy Consumption Problem	Reduced Energy Payment and Load	UC and PAR not Measured
ToU and Small HEM [4]	Lessening in EC	Decrease EC	Disregard UC and not Simplify How Much EC Minimized.
QEC Management for Different Housing Loads [5]	Residential SG Networks	Delay Decrease and Cost Minimization	Do not Consider PAR and RES
Manageable Load Modules [6]	GSO for Constraints and Multiple Problems	Technique for Shiftable Problem is Proposed	PAR and UC not Considered
Dynamic Formation for SG and Operational Strategy [7]	Alter Movement Network	Alter Circulation Network from Passive to Active	Single grid for hourly demand
Heuristic algorithm [8]	Planning Load	Accessible Computational Behaviour	Deliberated Only US
Short-term Scheduling [9]	Planning of Circulated System is Investigated	DGO and DisCo are Optimized	Short-term Scheduling is Considered
AFC-STLF for SG [10]	Forecasting the Next Day Load	Decreasing Energy Execution and Downsize Input	Forecasting for not More than Two Days
Cuckoo, GA, BPSO [11]	Use of RES Energy and Grid Optimally	High Peaks and Electricity bill	Unnoticed PAR and UC
Hybrid TLBO [12]	Reducing Electricity Cost and User Discomfort	Achieved Anticipated UC and EC	Unnoticed WT

separate micro grid in [7]. To meet the hourly demand the suggested policy is more tested on cost-effective aspects of generation throughout the arrangement period and consumed HSA showed competent results in detecting the ideal position of DER in the distribution network for lessening energy fatalities. Heuristic and exact algorithms for load scheduling under RTP from utility work is proposed by authors of [8]. The offered algorithm achieved within 5% of the ideal cost than the offered precise algorithm. In [9], authors deliberated two diverse test structures to investigate the incremental price for a short term arrangement of a dispersal system with DG entities and presented three altered situations with several methods through improving benefit functions in the multi-objective optimization framework. The AFC-STLF ideal is proposed in [10] which estimates the days load on the foundation of padded input examples till the recent day. Hybrid algorithm TLGO is proposed in [12], to lessen electricity intake cost and maximizing consumer comfort. The proposed hybrid algorithm is compared with other techniques; the proposed technique maximized user comfort and minimized the cost without affecting PAR and peak power consumption.

III. PROBLEM STATEMENT

Authors in [11-14] have proposed energy management system for residential area. In order to achieve targeted objectives, authors have taken different scenarios under different price schemes. In [11-13], authors exploited GA and BPSO for energy management. In [11], authors also exploited Cuckoo and used ToU pricing scheme with three different cases, authors considered smart homes, smart homes with RES and traditional homes. Proposed techniques reduced electricity cost. In [13], authors also exploited and ACO under ToU pricing and IBR for electricity bill calculation for energy management and authors have taken single home into consideration. Authors proposed technique effectively minimize electricity cost and PAR. In [14], authors implemented HSA technique under ToU pricing scheme and taken single home into consideration, using above aforementioned technique minimize purchase of electricity during PH and peak power. However, there are some limitations in [11] and [13-14] which are as follow: Authors of [11], ignored UC and PAR. In [13],

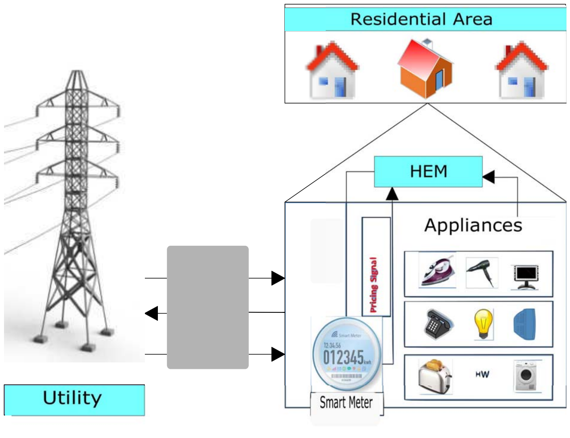


Fig. 1. Proposed System Model

author compromised on UC and security and privacy of user. Authors ignored efficiency and storage cost and considered only zero feed-in electricity in [14].

IV. PROPOSED SOLUTION

Main purpose of this work is to reduce PAR and cost by optimizing electricity consumption pattern. In this work we have taken 16 appliances which are further divided into three different sets, under ToU pricing scheme and taken single home as well as multiple homes under consideration.Also we have used meta-heuristic technique called HSA and PIO and compaired their results with our proposed scheme called HPIO. We have tested our proposed technique under three different OTIs which are 5 minutes, 30 minutes and 60 minutes. To minimize electricity cost we schedule each appliance in a time slot, where power rating and status are attributes associated with each appliance.

V. SYSTEM MODEL

In this research work we have deliberated smart home and proposed HEMS to schedule smart appliances to minimize PAR and cost. Smart home is well-found with smart appliances like SM, the advanced both way communication network and EMC. SM is used as a bridge between utility and consumer. EMC receives the energy consumption pattern of all smart appliances for scheduling according to their pricing signal which is ToU in our case where SM acts as a bridge; it sends price signal received from utility to EMC and energy consumption data from EMC to utility. Communication between utility and EMC is done using the advance communication network. In this research work single and multiple homes are considered equipped with 16 appliances and ToU is used to calculate electricity bill. In our scenario three different OTIs are used; in other words, 5 minutes, 30 minutes and 60 minutes scheduling horizon are used. In 5 minutes OTI a single day is divided into 288 equal time slots, 30 minutes OTI in which single day is divided into 48 equal slots and 60 minutes OTI in which a single day is divided into 24 equal slots and compared results in terms of cost, PAR, energy consumption and waiting time for all three scenarios. Smart appliances are classified according to their power consumption pattern for scheduling.

According to power consumption of appliances we divide them into three categories: Base appliances, interruptible and non-interruptible appliances.

A. *Load Categorization*

In our proposed system we have divided appliances into three classes according to their power consumption which are non-controllable, thermostatically and non-thermostatically manageable appliances. Each of them is explained as follows:

1) Non Controllable or Base Appliances: Also called fixed appliances are those appliances which are non-manageable. Total operation time of those appliance and energy consumption pattern cannot be changed. User can turn ON or turn OFF these appliances whenever he wants in other words, these appliances must be ON whenever the user turns them ON such appliances includes light, refrigerator.

2) Thermostatically Controllable or Interruptible Appliances: These appliances are also called manageable appliances because their operational time can be interrupted during their execution and can be shifted to any time slot. In other words, their operational time can be shifted and modified.

3) Non Thermostatically Controllable or Non Interruptible Appliances: Also called burst load appliances are manageable appliance however, works on predefined cycles. These appliances can be shifted to any time space when they are under execution they must fulfil their operating time without any interruption.

B. *Price Model*

Utility uses different dynamic pricing schemes like ToU, CPP, RTP, DAP, to calculate the price of electricity cost. These dynamic pricing schemes encourage consumer to change their loads from PH to OPH to reduce their cost. Among all aforementioned schemes we have use ToU pricing scheme in this work.

TABLE II Appliance Type

Categories	Appliances	PR (kWh)
Thermostatically Controllable	AC	2
	Electric Water Heater	2
	Iron	2.4
Non Thermostatically Controllable	Dish Washer	0.15
	Washing Machine	2.2
	Hair Dryer	1.8
	Hair Straightener	0.055
Non Controllable	Refrigerator	1.67
	TV	0.083
	Light	0.1
	Desktop Computer	0.15
	Telephone	0.005
	Oven	2.4
	Cooker Hood	0.225
	Toaster	0.8
	Kettle	2

C. *Optimization Technique*

For real time optimization, traditional optimization techniques like MILP, ILP and MINLP are not good enough to handle a large group of appliances so in my work we have used meta-heuristic algorithm HSA and bio-inspired PIO and compared their results with our proposed HPIO scheme to achieve our objective. Considered techniques are discussed in detail.

1) PIO: PIO is proposed by Duan and Quiao in 2014. The algorithm is derived from the behavior of homing pigeons. PIO consists of two models which are as follow, the landmark operator and compass operator, as comparing with other algorithms PIO has better convergence speed and optimization performance. In PIO initially population is generated randomly and to reach gbest following strategy is adopted

2) Map and Compass Operator: After initilization, pigeons are not familiar with the destination or landmark, so they find out the position and the flying direction with the help of magnetic field and position of the sun. In this model, each pigeon renew its position according to the new global optimal solution in the current iteration. On the consideration that the position and speed of the j^{th} pigeon are M_j and O_j respectively, M_j and O_j are updated according to Equations (1) and (2) in the t^{th} iteration.

$$O_j(t) = M_j j(t-1) e - Gt + rand(M_g - M_j(t-1)) \quad (1)$$

$$M_j(t) = M_j(t-1) + O_j(t) \quad (2)$$

Algorithm 1 PIO Algorithm

```
Input maximum iteration,
Initialization: pigeonnum, D, map and compass
Factor, T1, T2,$M_g$
Specify LOT of appliances and power ratings
Set initial path $M_i$ and velocity O for
Each appliance
Randomly initialized the population
Set $M_p$= $M_i$
Calculate the fitness of individual
appliances
Find the optimal solution
Map and compass operator
for l=1:T1 do
    for i=1:pigeonnum do
        while $X_i$ is beyond the search range do
            Calculate $M_i$ and $O_i$
    for j=1:D do
        while $M_P$ is beyond the search range do
            sort all the appliances according to
            their fitness values
            Pigeonnum=pigeonnum/2
            Keep half of the appliances and
            discard the other half
            $X_c$= Average of the remaining
            appliances
            Calculate $M_i$
    Output: $M_g$ is output as the global optima
    of fitness function
```

3) Landmark Operator: After sometime, when sone of the pigeons finds known location or landmark. Thus, these pigeons can move to the place faster, and the others follow them. On the assumption that M_c(t) is the center of the position of the pigeon whose fitness is the top N_p/2, the position of each pigeon in the t-th iteration is

$$N_p(t) = N_p(t1) \div 2 \quad (3)$$

$$M_c(t) = \sum M_j(t) fitness(M_j(t)) - \Sigma fitness(M_j(t)) \quad (4)$$

$$M_j(t) = M_j(t-1) + rand(M_c(t) - M_j(t-1)) \quad (5)$$

where the number of pigeons is represented by N_p(t) that meets the restriction of the condition in the t-th iteration and fitness(M_j(t)) is the proportion of the fitness of the j^{th} pigeon to that of all the pigeons. In the minimum optimization problem, the fitness is formulated as follows:

$$fitness(M_j(t)) = 1f(M_j(t)) + \varepsilon \tag{6}$$

Where, f is small value used as fitness function.

Algorithm 2 HPIO Algorithm

```
Input maximum iteration,
Initialization: pigeonnum, D, map and compass
Factor, T1, T2,$M_g$
Specify LOT of appliances and power ratings
Set initial path $M_i$ and velocity O
for each appliance
Generate initial Population using HM
Set $M_p$= $M_i$
Calculate the fitness of individual appliances
Find the optimal solution
Map and compass operator
for l=1:T1  do
    for i=1:pigeonnum do
        while $X_i$ is beyond the search range do
            Calculate Mi and Oi
    for j=1:D  do
        while $M_P$ is beyond the search range do
            Sort all the appliances according to
            their fitness values
            Pigeonnum=pigeonnum/2
            Keep half of the appliances and
            discard the other half
            $M_c$= Average of the remaining
            appliances
            Calculate $M_i$
    for itr=1:Max iteration do
        for j=1:12 do
            Improvise new harmony xnew
            if rand() < HMCR then
                Choose value from HM
                if rand() < PA then
                    Adjust value
                else
                    Choose a random value
    Output: $M_g$ is output as the global optima
    of fitness function
```

4) HSA: HSA is a meta-heuristic technique offered by Geem in (2001), motivated from the musical exercise of finding for a fine form of harmony, in this music managing, all performers sound pitches inside potential series together to create one harmony. If all pitches together create a better coherence, than each musician stores that in his memory and probability of new harmony is developed next time.

Algorithm 3 HSA Algorithm

```
Initialize all parameters
Generate initial harmony memory
Evaluate fitness of initial memory
for i=1:T1  do
    for itr=1:Max iteration do
        for j=1:12 do
            Improvise new harmony xnew
            if rand() < HMCR then
                Choose value from HM
                if rand() < PA then
                    Adjust value
                elseChoose a random value
    Perform selection
    Compare $xnew$ with $xworst$
    if f($xnew$) < f($xworst$) then
        $xworst$ = $xnew$
    else
        Keep existing
```

The Similar process is followed in Controlling as well, where the early solution is produced arbitrarily from decision variables within potential choice, if an impartial function of this decision variable is better to create an optimistic solution then chances to create new better solution is improved. To generate new harmony we go through three steps which are as follow

- HMCR
- Pitch adjustment
- Random selection

Initially HM is generated randomly between [0, 1], using following equation :

$$x_{(i,j)} = l_j + rand().U_j - l_j \tag{7}$$

If random number is less than HMCR then from a new vector the first verdict variable is arbitrarily chosen.

$$V_{i,j} = \begin{cases} x_(randj) & if\ randb()\ is < HMCR \\ l_j + rand().U_j - l_j & else \end{cases} \tag{8}$$

$V_{(i,j)}$ in the above equation shows j^{th} element of the initial harmony memory. rand() function generates random values between 0 and 1 whereas U_j and l_j are upper and lower bound respectively.

Elements selected from HMCR are further modified to the pitch adjustment rate.

$$V_{i,j} = \begin{cases} V_i^j rand().bwj & if\ rand()\ is < PA \\ V_i^j & else \end{cases} \tag{9}$$

Once new harmony vector is generated, it is then compared with the poorest harmony in HM and checked that new harmony is improved than worst harmony or not if new harmony is improved than replace it in HM. These improvisation processes continue till a termination criteria is meet. In our scenario harmony is a time slot where each bit of harmony represents an appliance. Here we are using 16 appliances; hence harmony consists of 16 bits which are either 0 or 1 show ON or OFF status of an appliance.

5) HPIO: In this section, we have discussed our proposed hybrid scheme in detail. In HSA initial population is generated using equation above, which is further processed and new harmony vector is generated using PA, HMCR and random selection. Finally, population is updated by comparing new and worst harmony. Moreover, in PIO initial population is generation using two constants between 0.1 and 0.9 randomly. Furthermore, to reach optimal position, magnetic compass and solar operator strategy is adopted.Finally population is divided in half, fitness function is calculate and selection is carried out. In our proposed HPIO, we have used best flovors of both techniques PIO and HSA, which results in better performance. In HPIO, HSA based initial population generation is adopted using equation :

$$\chi i_j = l_j + rand() \cdot (\upsilon_j - l_j) \tag{10}$$

and PIO based strategy for best population is adopted, which is further modified using PA and HMCR.The detail steps of hybrid algorithm are illustrated in algorithm 2.

VI. SIMULATION AND RESULTS

In this section simulation results are discussed in detail. To evaluate the performance of our proposed technique, we conduct our simulations in MATLAB. Algorithms are evaluated on the bases of electricity cost, energy consumption, PAR and user comfort. For optimal scheduling for single smart home, we consider a single and multiple homes consisting of 16 appliances. However, this task (scheduling) can be done over multiple Appliances are categorized into three different types. All type of appliances along with their power rating are shown in TABLE II. The day is divided into hourly,30 minutes and 5 minutes time slots. Simulation results for our designed objectives are discussed in the following subsections.

A. Load

We have used ToU rating pattern to calculate the cost of energy bill. In ToU hours are divided into the blocks of fixed price for PH and OPH. HSA, PIO and our proposed HPIO scheduled appliances to shift from PH to OPH. The results illustrate that the HPIO scheduled load in an efficient way, in 60 minutes and 5 minutes OTI as compared to the HSA, PIO and unscheduled load, while PIO performen better under 30 minutes OTI as shown in figure 5.

The results shows that the HSA and PIO schedule load in an efficient way as compared to the unscheduled load. Overall power consumption is low as HSA and PIO avoid peak formation in a particular slot of a day. From the results we can say that HSA and PIO improves the daily energy consumption pattern of appliances by shifting a load from PH to OPH.

B. PAR

Peak is never good for both consumer and utility because the consumer has to pay extra while utility has to meet an extra power requirement. In our proposed scheme HPIO and PIO avoid peaks formation under 60 minutes and 5 minutes OTI's. PAR reduction can be seen for each case in figure 4, while for multiple home Figure 8 shows PAR reduction for 10,30 and 50 homes.

C. UC

UC is related to both waiting time and electricity cost. In our work, user comfort is calculated in terms of waiting time (how much user waits to turn on an appliance). Maximum UC will increase the cost and reduce the appliance delay accordingly. The more delay results in reduced UC.

Figure 2, illustrates the average waiting time of each appliance type. From the figures we can clearly see that under all three cases HPIO performed better in reducing waiting time also waiting time against for multiple homes is shown in figure 6.

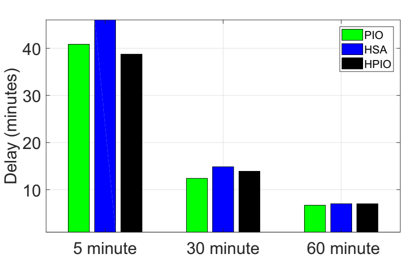


Fig. 2. Delay against Different OTIs

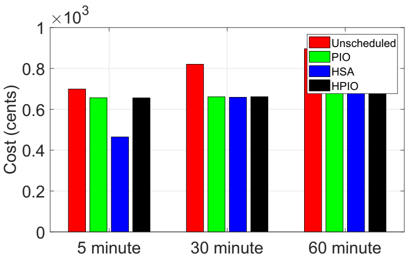


Fig. 3. Cost against Different OTIs

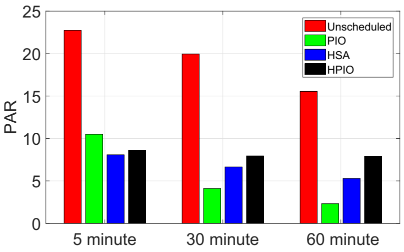
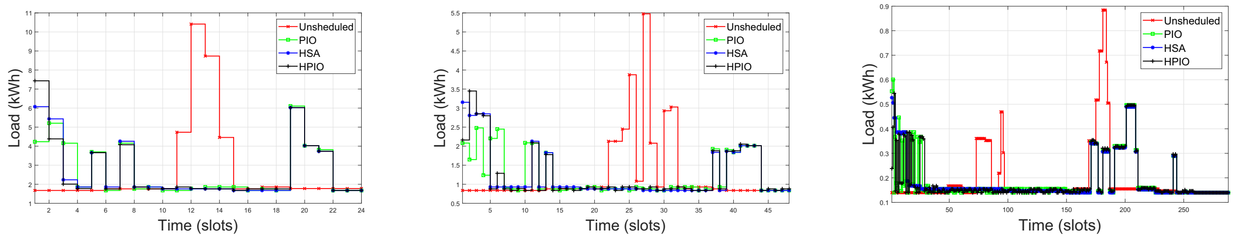


Fig. 4. PAR against Different OTIs



(a) Load for 60 Minutes OTI

(b) Load for 30 Minutes OTI

(c) Load for 5 Minutes OTI

Fig. 5. Load against different OTIs

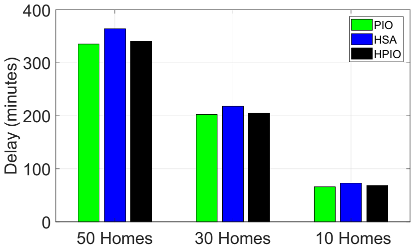


Fig. 6. Delay for Multiple Homes

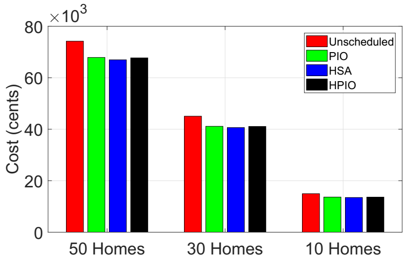


Fig. 7. Cost for Multiple Homes

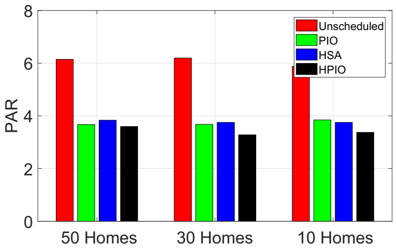


Fig. 8. PAR for Multiple Homes

D. Total Cost

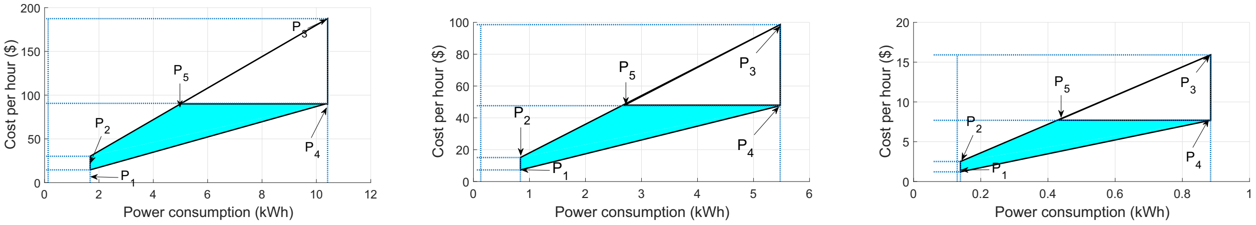
There is always trade-off between UC and cost. HSA, PIO and HPIO performed improved in minimizing of total cost drop as compared to unscheduled cost.However, HPIO outperformed in terms of UC. Cost reductions can be seen for each case in figure 3 and cost against multiple homes can be seen in figure 7.

E. Feasible Region

Feasible region or search space is an area defined by specific set of points of all optimization problem in which objective function satisfies the result and few specific points are constraints of the problem. In our work we defined feasible region of a cost function for single home. Feasible region against different OTI's can be seen in figure 6, where P1,P2,P3,P4 and P5 have shown fesible region within different OTIs.

F. Performance Trade-off

There is a trade-off between the waiting time and the cost.In other words cost and waiting time are inversely proportion to each other, if consumer compromise and wait he will have to pay less cost otherwise, to achieve higher UC user have to pay extra cost. We have compared UC and cost by using HSA, PIO and HPIO over unscheduled load.



(a) Feasible region for 60 minutes OTI (b) Feasible region for 30 minutes OTI (c) Feasible region for 5 minutes OTI

Fig. 9. Feasible Region against Different OTIs

VII. CONCLUSION

In this work, our scientific contribution include evaluation of HEM under ToU pricing scheme on the basis of HSA, PIO and HPIO proposed in this paper. We take single and multiple homes consisting of 16 smart appliances with different power rating and classification for simulations to show efficiency of our scheme. Our proposed scheme is evaluated in terms of PAR, cost and UC, which is measured in terms of waiting time. Simulations results show that proposed techniques HPIO perfomed well in reducing waiting time and PAR then HSA and PIO. However, there exist trade-off between UC and cost.

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