Resource Balancing Scheduler Implemented as an Anticipatory System in Power Management

SAMUEL MATTHEW DUMLAO, ROSULA REYES
Department of Electronics, Computer and Communications Engineering
Ateneo de Manila University
Loyola Heights, Quezon City
PHILIPPINES
smdumlao@gmail.com, rsjreyes@ateneo.edu

Abstract: - Power generation, transmission, and distribution infrastructures are built with the goal of satisfying the peak load. Consumers are deprived of this information; thus, they are incapable of helping the power companies in mitigating the problem. However, several power companies with some support from their government around the world has started to offer time-of-us (TOU) tariff to include the consumers in mitigating the problem on energy security. Through TOU, the consumer is informed when power consumption is high and how this translates to power prices.Lack of knowledge and tools for TOU may cause confusion whether this will be beneficial or not to the consumer. In anticipation for TOU implementation in the Philippines, the study explored the usage of a resource balancing scheduler to aid the user during the planning and execution stage of managing their power consumption. The system proved to be useful in providing a platform where users can plan, monitor, and adjust the schedule of their home appliances to maximize benefits of TOU.

Key-Words: -Power Management, Anticipatory System, RCPSP, Time-of-use Tariff,Resource Management

1 Introduction

Current power consumption consists of peak and off-peak loads, and power companies are focused on meeting the peak load. The challenge for the creation of energy infrastructure is that they must be designed to meet the peak demand rather than the average demand [1]. Power generation, transmission, and distribution infrastructures are built with the goal of satisfying the peak load. Consumers are unaware that the power prices are continuously increasing due to infrastructure development intended to satisfy the peak load, and they are deprived in many ways of the opportunities to participate in lowering the prices. Informing the consumers that power prices hinges mainly in the peak loads will enable them to reflect on how they are consuming power.

Peak demands can be mitigated by supply management, demand management and shifting the demand away from the peaks [1]. Countries like the United Kingdom have created incentive scheme linked to the generation of solar photo-voltaic at home to augment the power supply whether locally consumed or added to the grid [1]. This is one way of increasing the supply available for consumption. In contrast, demand management offers the ability to control the demand by providing the consumers real time pricing for them to adjust their consumption to off-peak hours for a lesser price [1]. Energy consuming tasks that do not require the involvement of the user to fully function or that can be scheduled at a particular time in the day can be schedule when the energy cost is lower [2]. By managing the demand, the investment in transmission and distribution grid is efficiently used through increased utilization [3].

Demand Side Management (DSM) allows the consumer to actively participate in the market, providing them the capability to manage their electricity consumption[4]. DSM uses automation technology to shift loads to find a match between the supply and demand [3]. There are many ways in which DSM can be beneficial to all sectors in the power industry but like any other tool, the crucial part is to understand the system. Consumer requires the proper information, education, and access to technology to make efficient consumption decisions [4].

Shifting loads with economic incentives seems to be logical but this can be complicated unless users are informed of the risk of spending more money. Some consumers might have difficulty in shifting their task and must opt-out from time-of-use (TOU) tariff [4].

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2 Problem Formulation

There are two problems being faced by nations trying to implement time-of-use tariff. On one hand, the user is not fully capable of realizing that they will benefit from time-of-use tariff. On the other, there is no mechanism that enables the user to maximize the cost benefit of time-of-use.

Therefore, the study aims to (1) create a scheduling algorithm that will balance power consumption and distance from a preferred start time, (2) test the scheduling system to guide users in deciding if they should use time of use tariff in cases when power companies offers the option to opt-out and (3) create a power management system where the user can plan, monitor, and adjust their appliances to consume power depending on prices.

3 Resource Balancing Scheduler

The classical resource-constrained project scheduling problem (RCPSP) deals with scheduling a project with a set of task that requires resources with limited capacities [5]. In their formulation, Kolisch and Hartmann [5] aimed for the shortest make span to finish the project while maximizing the resource constraints. Hartmann [6] extended that formulation by the addition of changing resource availability and resource request as an additional constraint. The extended formulation maintains the focus on maximizing resources to minimize the project duration.

However, the importance of both time and resources should be explored for instances when resources are more expensive than time and finding balance must be explored. The Resource Balancing Scheduler explores the possibility of extending the formulation of RCPSP by giving more gravity in the expenses incurred by resources used in a project.

In project scheduling, it is crucial to understand the two types of resources involved. Renewable resources refers to resources that are replenishes with time or resources that is available at a constant volume per unit time. On the other hand, nonrenewable resources are resources that does not replenishes itself at a constant rate and is usually available for the whole duration of the project.

The main difference between solar power plants and coalpower plants is the fact that the former is a renewable resource since the sun is providing constant power while we are progressively depleting the our coal supply. However, renewable and nonrenewable resources are bounded by time and with proper time restrictions, a resource could be seen as renewable or nonrenewable. For an instance, the power generated from coal power plants are said to be renewable but when taken from the perspective of the power generator and household from an hourly perspective, the power can be seen as a renewable energy since it is being supplied at a constant rate. The scheduler assumes that the resources are replenished per unit time.

3.1 Scheduler

Based on the priority, the start time of each task is scheduled one at a time. The resource consumption of the scheduled task is deducted from the allocated power limit which in turn will affect calculation of the start time of the other task.

The scheduler weighs between the remaining power per time slot and distance from preferred start. It will provide the start time with the best qualification based on the criteria. It starts by calculating the remaining budget of the system if that start time is selected then calculate the distance from the preferred start which is done for all the valid start. It will then select one based on the criteria calculations.

In the calculation of the best fit, the algorithm takes into consideration the weights assigned by the user to the cost and distance metric. The user has the ability to swing from fully depending on the cost metric until fully depending on the distance metric. In between extremes, the user could find his ideal weights combination.

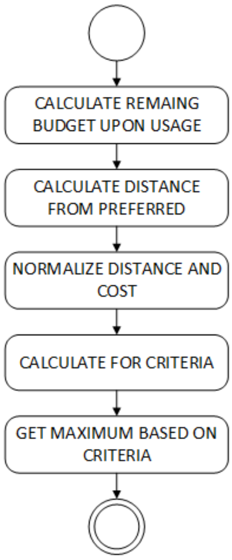

Fig.1. Start Time Selector of the Scheduler

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Fig.2. Task Scheduling for task with the same duration and load using the parameters 0, 0.625, and 1,respectively.

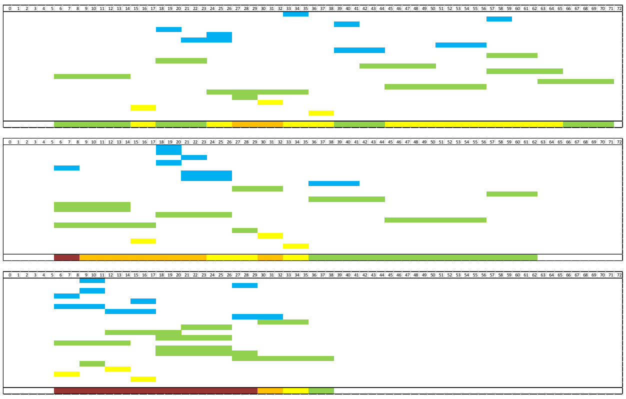

Fig.3. Task Scheduling for task with different duration and load using parameters 0, 0.5, and 1, respectively.

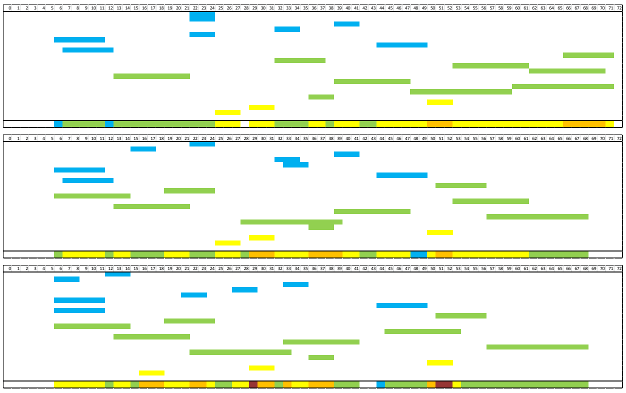

Fig.4. Task Scheduling for task with different duration and load with start time using parameters 0, 0.5, and 1, respectively.

The balancing between cost and preferred time start can clearly be seen in Fig. 2. The tasks have the same duration and load, and they all want to start at the same time. As the parameter increase towards 1, the scheduler behaves towards the behavior of the classical RCPSP where as long as there are resources, it will schedule task. On the other hand, the task are spread throughout the whole project duration when the parameter is at 0 representing the time when the spreading the cost has more gravity in the decision. The schedule in the middle represents the possible compromise during scheduling.

Scheduling in Fig. 3 depicts more realistic values where the task has varying load and duration. The colors represent increasing load of each task ranging from blue to red with red as the highest. The last row represents the accumulated consumption of all the loads. As the parameter increase from 0 to 1, the accumulated consumption per unit time increases which can clearly be seen in the amount of red regions. Similar to the previous scheduling, the task starts earlier as the parameter increases.

Hartmann [6] introduced the possibility of picking different time start. The schedule in Fig. 4 explores having different start time in contrast to the classical RCPSP having the tasks start at the start time of the project. Although it can be quantitatively verified through the standard deviation of the remaining power, which is decreasing as the distance parameter is reduced, that the scheduler is achieving a more tighter resource usage, visually, there is very little change in the scheduling. In contrast to having only one start time, the scheduling where the decision is solely based on satisfying the earliest start time, the schedule does not pile up in any particular time slot. This can attributed to the effect given by the start time set by the user which could be the result of previous knowledge that distributing the start time in such a manner will produce a more even scheduling.

The effect of the start time can be verifying by testing the scheduler in condition with overlapping start time. As seen in Fig. 5, there is an increase in the number of orange regions as the parameter increases. However, power consumption is still distributed since the overlap is distributed.

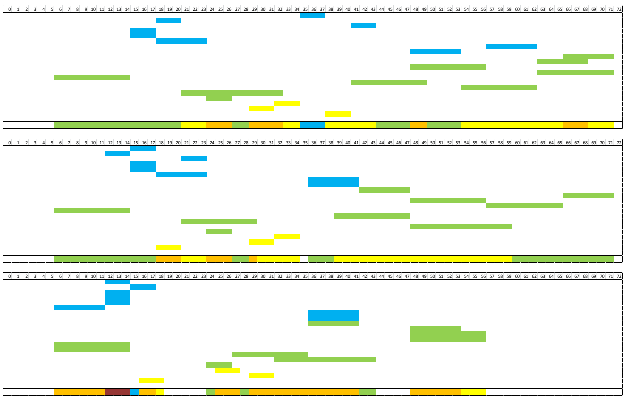

Fig.5. Task Scheduling for task with different duration and load with overlapping start time using parameters 0, 0.5, and 1, respectively.

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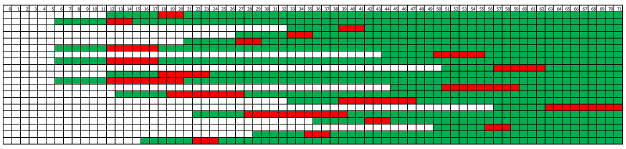

Fig.6. Project Schedule input with Varying Start Time and Preferred Start Time

The concept of preferred start time is also incorporated in the scheduler to provide more flexibility. This will allow the schedule to shift from right to left depending on the balancing metric used. The user could schedule a task that could start earlier than his preferred start and the system will generate a schedule closest to the preferred start.

Fig. 6depicts a scheduling input where there are varying start time and existence of a preferred time start. The green time slots show where the task can be scheduled. This begins from the start time to the latest start. The latest start refers to the last start time that will end the task before the intended finish time. The preferred time start is depicted by the start of the red time slots. The whole red time slots refers to the preferred schedule that begins from the preferred time start until the duration of the task is finished. A preferred time slot that is later than the start time provide more flexibility since the schedule can still shift to the left or right depending on what the scheduler calculate to be the most ideal case to balance the task.

3.2 Priority Rule Heuristic

Since the order in which the tasks are scheduled affects the scheduling, it is crucial to take into consideration factors that might affect the scheduling. The efficiency of scheduling bigger task first before scheduling smaller task is better than scheduling task without taking into consideration the characterization of the task.

In this formulation, the tasks are characterized based on three factors, and a metric was developed to balance the effect of this three metric. Three factors were considered namely the resource consumption of the task, the duration of the task, and the swing or flexibility of the task.

Task with low load, short duration, and high flexibility are easier to handle compared to task with high load, long duration and low flexibility since the former can easily fit into scheduling gaps. It is therefore logical to schedule task with high load, long duration, and low flexibility first. However, those two types of task represent both extremes of the characterization and there is a number of combination between them.

Table 1. Keys Used in Finding the Balance between the Load, Duration, and Swing

Load	Duration	Swing
0.00	0.00	1.00
0.00	0.33	0.67
0.00	0.50	0.50
0.00	0.67	0.33
0.00	1.00	0.00
0.20	0.40	0.40
0.25	0.25	0.50
0.25	0.50	0.25
0.33	0.00	0.67
0.33	0.67	0.00
0.40	0.20	0.40
0.40	0.40	0.20
0.50	0.00	0.50
0.50	0.25	0.25
0.50	0.50	0.00
0.67	0.00	0.33
0.67	0.33	0.00
1.00	0.00	0.00

A set of keys were develop giving weights in the amount of {0.0, 0.5, 1.0} to each characterization. This yielded into 27 possible combinations but was reduced to 18 upon cancelling combinations that has the same effect when normalized. An example of these duplicate keys are {1.0, 1.0, 1.0} and {0.5, 0.5, 0.5} which gives each task equal weights to each characterization. The values in Table 1 shows 18 combination of the keys used to schedule the task to find the best fit. All the values are normalized.

With a set of keys, the priority rule heuristic can narrowed down the solution into 18 different possible combinations. Fig. 7 shows the flow of determining the order of ranking where candidates are initially selected and their corresponding load, duration, and swing are normalized. Based on the keys, the criteria is calculated and finally ranked. The one with the highest value is considered to be the most difficult to schedule and will be scheduled first.

As seen in Fig. 8, prior to scheduling, an activity list was generated. This is the ranking of the candidate tasks that are to be scheduled based on the characterization key that was used. The characterization did not take into account the priority assigned by the user since this is a biased assignment and will not aid in the characterization of each task.

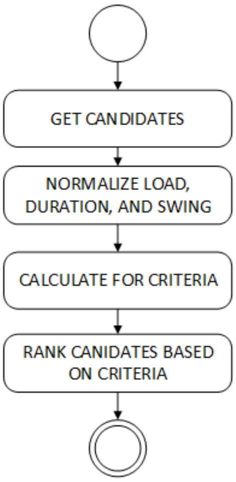

Fig.7. Priority Rule Heuristic Calculation

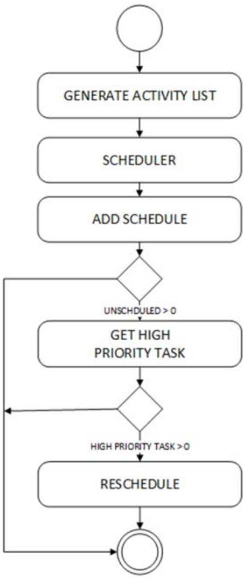

Fig.8. Implemented Scheduling Flow Taking Into Consideration Unscheduled High Priority Task

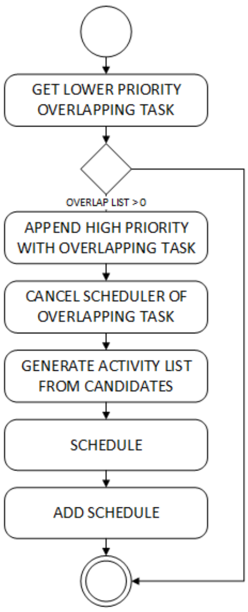

Fig 9.Rescheduler Algorithm triggered when there is a High Priority Task in the List of Unscheduled

However, the satisfaction of the user is crucial in the scheduling.Therefore, the scheduling implemented a high priority rule where task with user priority higher than a set value should always be scheduled. If there are unscheduled high priority task, it will trigger a reschedule. If the user set that high priority task are task with the value higher than 5 in the range 1-10, when the system was able to identify that there is a priority 6 in the unscheduled, it will trigger a reschedule.

As seen in Fig 9, rescheduler will not reschedule all tasks; rather, it will first pick the best start time based on the distance from preferred start and remaining power. It will then schedule that it will use that slot. This is done for all high priority tasks that are unscheduled. The algorithm will then determine task that are overlapping with this time slots and cancel the scheduling of those task. The unscheduled high priority and the cancelled task are then used as candidate task and will undergo scheduling again. In contrast to before, the order of scheduling is now fully dependent on the user's priority. This is to ensure that the user's priority is taken into consideration while finding the optimal scheduling depending on the characterization of the task.

In evaluating the benefit of using the priority rule keys, a random task generator was developed following the restrictions in Table 2. The task generator was run 1000 times through the scheduler with all the 18 priority rule keys. Perfectly scheduled tasks are awarded 1 point while fitted task are award 0.8 points. Since the aim was to prove the value of the keys, rescheduled task was not considered in the calculation of points.

Table 2. Task Generator Restrictions

	Min	**Max**
Resource	100	500
Start	6	70-duration
Deadline	preference + duration	70
Preference	start	70-duration
Duration	3	12
Priority	1	10

Table 3. Simulation Score Tally of the Different Priority Rule Keys

Max Power	**Best Min**	**Best Max**	**Worst Min**	**Worst Max**	**Best Average**	**Worst Average**	**Score Dif**
1000	16.2	20.0	12.8	20.0	19.4	17.6	1.8
800	15.0	20.0	11.8	19.8	18.4	16.0	2.4
600	11.6	20.0	8.8	18.8	16.6	13.7	2.9
500	11.8	19.2	8.6	17.4	15.5	12.3	3.2

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Table 3 shows that as the max power decreases, the score for both the best key and the worst key also decreases. This is logically correct since as the max power decreases, the number of task that can be scheduled also decreases. However, it is notable that the difference between the best average and the worst average increases as well. This suggests that as the scheduling load increases, the need for the priority key increases as well. The scheduling key will be crucial when there is a huge difficulty in schedule; thus, it served its purpose of attaining better scheduling.

The resource balancing scheduler can be used during planning and execution. With its capability to spread resource consumption, initial planning can be done to explore the resource limit that the user can agree to. By adjusting the balance between cost and preference, the user will have an idea how much power he will consume depending on the how comfortable he is with the scheduling.

During execution, the system could be used to maximize the allocated power by adjusting the balance towards the preferred start or the scheduled start. Since this was already preplanned, the system knows that the scheduled time start represents the optimal scheduling that the user wants. Using the scheduled start as the preferred start time during runtime and at the same time use full parameter that solely take into consideration the distance from preferred start, the system will reschedule, when needed, to the nearest available time slot to the scheduled time.

4 Residential Time-of-Use

Time-of-Use (TOU) service will be most beneficial to consumers who are capable of changing their consumption habits throughout the day to adapt to the flexible pricing[4]. To improve the flexibility of the user for schedule Anastasi[2] realized that some energy consuming task that do not require user involvement can be scheduled during parts of the day where the energy cost is lower.Gottwalt et al.[3]explored more on how smart appliances will help the consumers to interact with the producers. However, such implementation will require the user to implement automation which could lead to further expenses.

The work of Giorgio et al [7]was aimed at creating a system that maximizes customer economic saving while preserving user preference and quality of experience. They wanted to create a system that generates the best time to run plannable loads according to time varying energy prices taking into consideration a power threshold and the estimated power consumption from nonplannable loads.

In scheduling household appliances, there are two types of loads that must be taken into consideration. Non plannable loads are appliances that cannot be shifted and can only be monitored [7], [8]. On the other hand, Plannable loads are appliances that can be shifted by choosing start time or expected time to finish [8]. It can be switched on or off without damage and degradation of consumer quality of experience [7]. The benefits of TOU are deeply rooted in these two types of tasks.

If these plannable loads can shift 20-40% of all the electricity use during offpeak hours, the user can reap the benefits of TOU [4], [9]. However, if for some reason like working at home forces the user to use power the whole day, TOU will not be beneficial [9].

For simulation purposes, let’s assume that a household has a monthly consumption of 200kwh which translate to roughly 7kwh per day. Assume that there are 17 peaks hours between 5AM and 10PM and 7 off peak hours from 10PM to 5AM. To maximize the benefit of TOU, 40% of the consumption must be during off peak hours. That translates to 250wh consumption during peak hours and 400wh consumption during off-peak hours totaling to 4250wh and 2800wh, respectively. This two values will then be used a power limitation for the scheduling algorithm used. However, the user realized that he sleeps between 2AM and 8AM effectively cutting all major power usage. There are now 15 hours of peak time and 4 hours of off-peak hours which compute to average usage of 283wh and 700wh. Based on these facts, the user decided that he is willing to allocate 350wh and 800wh maximum for power usage. With these values, the scheduler can be used to calculate for the scheduling based on the maximum power seen in Fig 10.

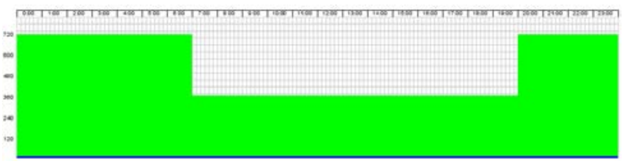

Fig 10. Simulated Power Limitations

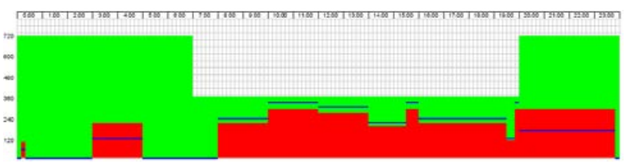

Fig.11. Sample Scheduling following the Assigned Maximum Consumption

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5 Anticipatory System

GreenFinder was developed with resource balancing scheduler in mind. The full implementation of the system includes monitoring, control, scheduling, anticipatory, and notification system. The monitoring and control require Zigbee to wirelessly transfer information. The remaining subsystems are implemented using Processing and is currently running under windows OS environment.

5.1 Hardware

The wireless capability of the implemented system utilizes MaxStreamXbee modulesthat perform the functions of a Zigbee module. Zigbee is a low data rate, low power consumption, low cost, wireless networking protocol that aims to be used in automation and remote control set-ups [10]. It is expected to provide low cost and low power connectivity for devices that requires long battery life ranging from months to two years but has little demand on data transfer unlike Bluetooth [10].

A Zigbee network is composed of three components namely: Coordinator, Router and End Device. A Zigbee network always has coordination because it is responsible for forming the network, handling out addresses and managing other information related to the function of the network [11].

The coordinator of the established Zigbee network is connected the computer running the processing software. This acts as the sink node that is capable receiving information from the monitoring node and transmitting commands to the control nodes.

The monitoring node is developed using a locally available power meter. The power meter outputs the data via RS232 protocol which is directly compatible with Arduino Uno. The TX pin of the power meter is connected to the RX of the arduino. Since the design takes into consideration multiple power monitoring sensor, parsing the data before transmitting it is essential to the design. The arduino receives the data from the Power Analyzer and build the send command for the Xbee. The Xbee is set-up in API mode where it will receive transmit command followed by the data to be transmitted. In this case, the data is the exact values gathered from the power analyser.

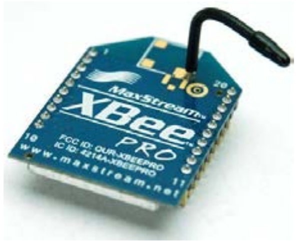

Fig.12. MaxStreamXbee Modules used for Wireless Transmission

Fig.13. Locally Available Power Meter used to monitor real time power consumption

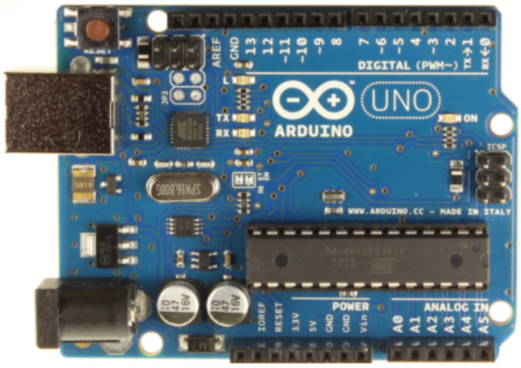

Fig.14. Arduino Uno used to Parse Data from Power Meter

One of the good things about the XbeeZigbee radios is its standalone capabilities. In the design of the controller nodes, which are capable of sending commands to turn on or off a Solid State Relay(SSR). The SSR is capable of accepting 5V logic and controlling 220V devices under 10A maximum rating. The Xbee can be deployed without a microprocessor since there are API commands that can turn on or off digital pins in the radio. This digital pin is the only control command that the control nodes need.

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5.2 Software

GreenFinder has four major tabs that are crucial during planning and execution. During planning, the task tab and plan tab represents the user input capabilities. The schedule must be executed first before the user have access to the monitor and adjust tabs. However, during execution, the plan tab is inaccessible because the user is only allowed to adjust the schedule using the schedule tab.

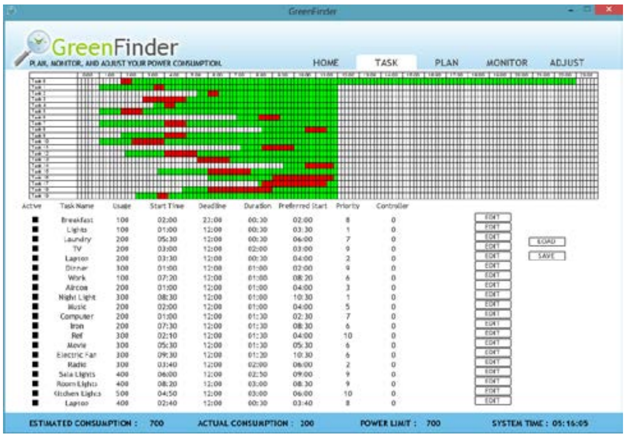

Fig.15. Task Tab of the GreenFinder

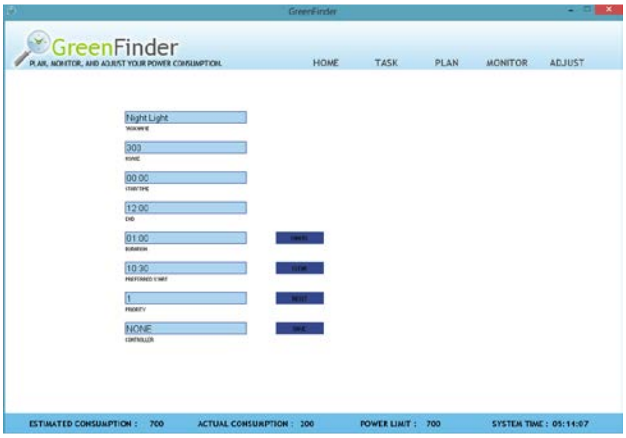

Fig.16. Edit Task

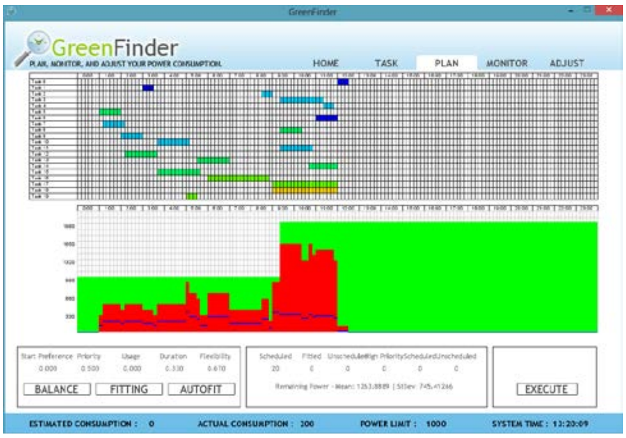

Fig.17 Plan Tab of the GreenFinder

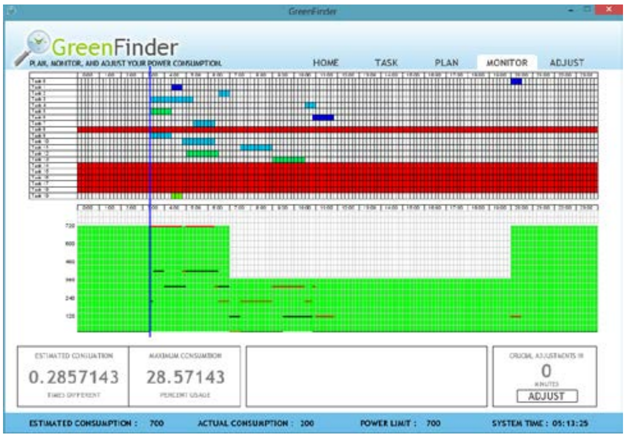

Fig.18. Monitor Tab of the GreenFinder

The task tab seen in Fig. 15 shows the list of task that can be scheduled. The active check box allows the user to choose among the list which task will be included in the scheduling. The remaining column serves as display of the actual values of each task. Using the edit button for each task, the edit function seen in Fig. 16 allows the user to edit their task list. Once the user is satisfied with the list of activities to be scheduled, the user should now proceed with the to the plan tab where the resource balancing scheduling is implemented.

In the plan tab, there are several buttons available for the user to adjust the schedule. The balance button increments the parameter that balances the cost of usage and distance from preferred start by 0.1 per button press effectively allowing the user to have 10 options. The fitting button cycle through the 18 priority rule keys. The Autofit tab runs the scheduling for all the 18 keys and picks the one with the best scheduling score. This will yield the schedule with the most number of schedule task. Finally, the execute button runs the system and immediately transfer the tab state to monitoring.

In the monitoring tab, there are two major graphs. The one on top refers to the scheduling that was implemented through the planning stage. Each schedule is represented using color values ranging from blue towards red. This is to visualize the data of the task without looking back into monitor.There is timeline that shows where the schedule is already running. This tab also calculates for the difference between the estimated consumption vs actual power consumption. This is essential since this affects the anticipatory subsystem.

The last tab in the system offers the user to reschedule task that have not started yet. Instead of rescheduling all the task, only those specified are entertained. Once the task is available, it proceeds in scheduling

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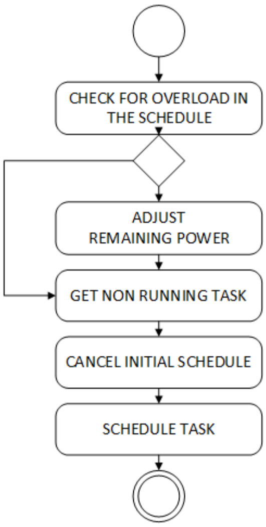

Fig.19. Aticipatory Algorithm

Scheduling task allows the system to have a look forward capability. The difference between the estimated consumption and the actual consumption are calculated at the beginning of each time slot. The difference is used to anticipate overload in the next two hours. If there is an overload, the system will trigger a reschedule. All tasks that are not currently running are included in the new candidate list for rescheduling. Prior to rescheduling, the schedule of these tasks should be cancelled first. After which, the system schedules the task.

Theanticipatory algorithm changes the preferred start of the user into the one that was scheduled. The scheduler is parameterized to use only distance from preferred start as a metric to yield a result that is closest to initially scheduled task. Since this function is automated, the schedule that the user assigned should be follow.

In instances when the actual consumption is below estimated consumption, the anticipatory system reschedules and attempts to go back to the original schedule assuming there was a reschedule triggered by a detected overload in previous timeslots. This serves as a checking mechanism for the anticipatory system for instances when the previously detected overload is no longer available.

5 Conclusion

The Resource Balancing Scheduler that was developed is capable of scheduling task based on the load, start time, end time, duration, preferred start, priority, and scheduling parameters. The scheduler is capable of balancing the resource consumption and distance from preference time. With the priority rule heuristic, it was then able to find keys that will provide a better scheduling order based on the load, distance and swing of the system.The design was initially focused on using it for power management but it will work with any renewable resources.

The scheduler was then tested to guide users on residential time-of-use tariff. By changing the maximum power consumption of the scheduler to the one needed to maximize TOU, the scheduler can be used to schedule task that will allocate power according to the amount of power remaining in the system.

Finally, the power management system with an anticipatory system was developed to aid the user in maximizing the benefit of TOU using the resource balancing scheduler. The anticipatory system served as a checking mechanism preventing the system to go beyond the maximum consumption.

References:

[1] S. Ahmad, “Smart metering and home automation solutions for the next decade,” *2011 Int. Conf. Emerg. Trends Networks Comput. Commun.*, pp. 200–204, Apr. 2011.

[2] G. Anastasi, F. Corucci, and F. Marcelloni, “An intelligent system for electrical energy management in buildings,” *2011 11th Int. Conf. Intell. Syst. Des. Appl.*, pp. 702–707, Nov. 2011.

[3] S. Gottwalt, W. Ketter, C. Block, J. Collins, and C. Weinhardt, “Demand side management — A simulation of household behavior under variable prices,” *Energy Policy*, vol. 39, no. 12, pp. 8163–8174, 2011.

[4] Australian Energy Market Commission, “Power of choice review - giving consumers options in the way they use electricity,” 2012. [Online]. Available: http://www.aemc.gov.au/media/docs/Final-report-1b158644-c634-48bf-bb3a-e3f204beda30-0.pdf. [Accessed: 28-Jan-2014].

[5] R. Kolisch and S. Hartmann, “Heuristic algorithms for the resource-constrained project scheduling problem: Classification and computational analysis,” 1999. [Online]. Available: http://www.om-db.wi.tum.de/psplib/files/handbook1.pdf. [Accessed: 06-Feb-2014].

[6] S. Hartmann, “Project Scheduling with Resource Capacities and Requests Varying with Time Project Scheduling with Resource,” 2011.

[7] A. Di Giorgio, L. Pimpinella, A. Quaresima, and S. Curti, “An event driven Smart Home Controller enabling cost effective use of

electric energy and automated Demand Side Management," 2011.

[8] A. Di Giorgio, L. Pimpinella, and F. Liberati, "A model predictive control approach to the load shifting problem in a household equipped with an energy storage unit," *2012 20th Mediterr. Conf. Control Autom.*, pp. 1491–1498, Jul. 2012.

[9] Ombudsman Services Energy, "Our advice and quick guide to time-of-use tariffs." [Online]. Available: http://www.ombudsman-services.org/downloads/Timeofuse tarrifs advice.pdf.

[10] S. C. Ergen, "ZigBee/IEEE 802.15.4 Summary," 2004.

[11] R. Faludi, *Building Wireless Sensor Networks*. O'Reilly Media, 2010.

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