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An Efficient Approach for Home Energy Management System

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ABSTRACT: *Wireless Sensor Network (WSN) is used in the home appliances, an Extension of the Smart Grid. Here, the In Home Energy Management (iHEM) is developed to reduce real time pricing and energy expense. IHEM allow communication* between *the consumer and controller through Wireless Sensor Home Area Network (WSHAN). Main idea of In Home Energy Management (iHEM) application is to find solution for Optimization based Residential Energy Management (OREM) scheme and also to reduce the cost of energy usage at home. Comparison of iHEM and OREM is carried to reduce energy expense to ensure efficient demand – supply. Evaluation is done based on the performance of iHEM under the presence of local energy generation capability, real-time pricing, and for prioritized appliances to determine the cost of energy expense.*

KEYWORDS *TERMS*: Cost optimization, energy and demand management, home automation, smart grid, wireless sensor networks.

I. INTRODUCTION

A smart grid delivers electricity from suppliers to consumers using digital technology with two-way communications to control appliances at consumers' homes to save energy, reduce cost and increase reliability and transparency [1] [2]. Using wireless Sensor Networks (WSNs) has many benefits, including untethered access to information, support for mobility, reduced cost and complexity associated with wiring and maintenance, and support for interoperability. While many of these benefits apply to the grid, there are a number of challenges that remain. The milestone in the process of transition from the traditional grid to the smart grid is the integration of information and communication technologies (ICT) to the power grid. The advances in ICT can be employed to increase automation, integrate distributed renewable resources, secure the grid infrastructure, adopt electric vehicles (EVs), and enable efficient demand-side energy management. First, it has been hard to handle the large number of residential units without communication, sensors, and efficient automation tools. Second, the impact of demand response programs has been considered to be relatively small when compared with their implementation cost [3] [4]. However in the smart grid, smart meters, low-cost sensors, smart appliances, and communications set the stage for novel residential energy management techniques that involve communications and interaction between consumers, devices, and the grid.

II. WIRELESS SENSOR NETWORKS (WSNs)

A wireless sensor network (WSN) consists of spatially distributed autonomous sensors to monitor physical or environmental conditions, such as temperature, sound, pressure, etc. and to cooperatively pass their data through the network to a main location. Area monitoring is a common application of WSNs [5]. In area monitoring, the WSN is deployed over a region where some phenomenon is to be monitored. When the sensors detect the event being monitored (heat, pressure), the event is reported to one of the base stations, which then takes appropriate action. Monitoring the activities performed in a smart home is achieved using wireless sensors embedded within everyday objects forming a WSN [6] [7].State changes to objects based on human manipulation is captured by the wireless sensors network enabling activity-support services.There are three wireless standards appear to be strong candidates for smart grid applications [8]. These applications are Zigbee, WI-Fi, and Z-wave standards. Zigbee uses a duty-cycling principle to attain energy efficiency [9]. However, it has limited bandwidth since it has been initially designed for networks with low communication intensity. On the other hand, recently introduced ultra-low power Wi-Fi chips position Wi-Fi as a strong alternative with its longer lifetime than the conventional Wi-Fi and with its higher bandwidth than Zigbee and Z-wave. Zigbee Alliance [10] has developed Smart Energy Profile 2.0 to meet the needs of smart metering and AMI, and provide communication among utilities and household devices such as smart thermostats.

III. METHODOLOGIES

Various new methodologies have been developed in the smart grid [11] [12][14][15] to improve the energy efficiency by using the WSN and managing the power consumption in home appliances.New methodologies [12][13][14][15][16] describes about reducing the cost and effective utilization of energy recourses and real time pricing. A residential load control (RLC) is used to reduce total cost and peak-to-average ratio and the method implemented is Automated load control with LP based optimization then it also predicts the price of electricity

[11].The decision support tool (DST) is used to scheduling the distributed energy resources and the method implemented is practical swarm optimization. The scheduling can be done by time of unit (TOU) pricing [12].The neural network -based prediction approach to predict the day-ahead demand. According to the predicted demand, the schedule of the microCHP device in each house is optimized

[13].Optimal consumption schedule (OCS) [14] is used to reduce the total cost and peak-to-average ratio and the method implemented is game theoretic pricing and scheduling and it is proportional to daily load and generation cost.Appliance coordination scheme (ACS) is to reduce the total expense and load and the method is interactive demand scheduling and the pricing can be done through Time of Unit

[15] [16].Optimization based residential energy management (OREM) is the scheme to reduce the electric expense and method is based LP model. The main process is to make the appliance usage in optimize energy. Here the day can be scheduled into a time slot and make appliance in the optimize time pricing can be done through time of unit.

IV. IHEM APPLICATION

The aim of the iHEM application is decreasing the cost of energy usage at home while causing the least comfort degradation for the consumers. This scheme uses appliances with communication capability, a WSHAN, and a central EMU. The iHEM application is based on ACS of [15], which accommodates consumer demands at times when electricity usage is less expensive according to the local TOU tariff.

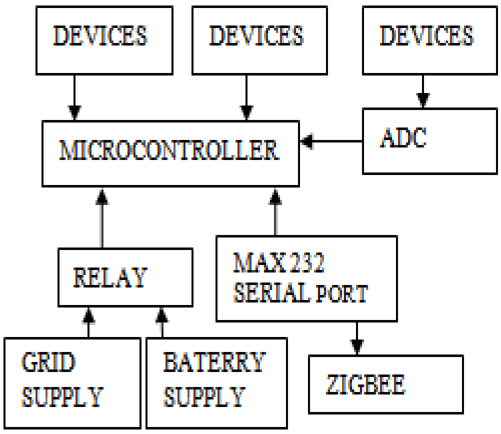

Fig. (1). Block diagram of iHEM

In the above diagram describes about the in Home Energy Management. It describes how wireless communication done between the appliances and energy management unit. It has a microcontroller it uses to control the system and have ZigBee it used to send or receive the signal. Three sensor device were connected to analog to digital converter first the sensor senses the physical signal into electrical signal it given to ADC it converts the analog signal into signal because the microcontroller receives the digital signal then the controller controls and monitor the signal and it transmits the signal through ZigBee. The ZigBee will act both operation of sender and receiver while sending it act as sender and receiver side it acts as receiver. For operation power supply is given to the microcontroller.In the iHEM application, consumers may turn on their appliances at any time, regardless of peak time concern, and the scheme suggests start times to consumers. Consumer demands are processed in near real time unlike the OREM scheme.When a consumer turns on an appliance, the appliance generates a START-REQ packet and sends it to EMU. The format of the START-REQ packet is given in Fig. 2(a). The first field of the packet is the Appliance ID.

Octets:

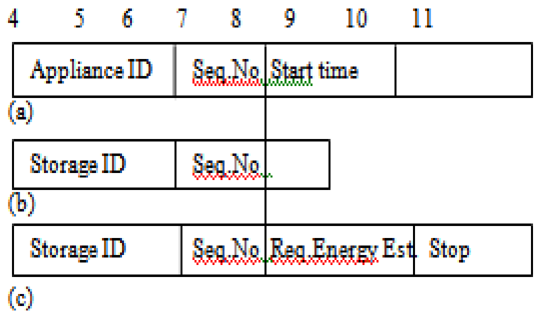

Fig. (2). iHEM packet formats. (a) START-REQ packet. (b)AVAIL-REQ packet. (c) UPDATE-AVAIL packet.

The sequence number field denotes the sequence number of the request generated by the appliance, since the appliance may be turned on several times in one day. Start time is the timestamp given when the consumer turns on the appliance. The duration field denotes the length of the appliance cycle. Each appliance has different cycle lengths. A cycle could be a washing cycle for a washer or the time required for the coffee maker to make the desired amount of coffee. This duration depends on the consumer preferences, i.e., the selected appliance program.Upon receiving a START-REQ packet, EMU communicates with the storage unit of the local energy generator to retrieve the amount of the available energy. It also communicates with the smart meter to receive updated price information from the utility. EMU and smart meter exchange packets periodically while EMU communicates with the local storage unit when a demand arrives. It sends an availability request packet, namely, AVAIL-REQ. The AVAIL-REQ packet format is given in Fig. 2(b). The storage ID field is the ID of the storage unit that is attached to the local energy generation unit. When the house is equipped with multiple energy generation devices such as solar panels and small wind tribunes, the amount of energy stored in their local storage units may have to be interrogated separately. In our application this field is used for inquiring the amount of available energy, hence it is a static value. However, other applications may also use this code field, e.g., to send a command to the storage unit to dispatch energy to the grid. Upon reception of AVAIL-REQ, the storage unit replies with a AVAIL-REP packet where the amount of Available energy is sent to the EMU.

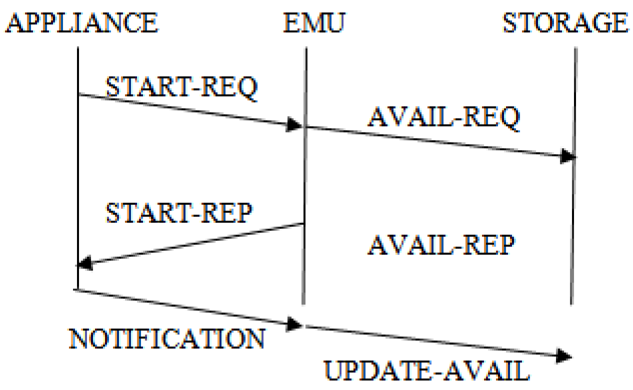

Fig. (3). Message flow for iHEM

After receiving the AVAIL-REP packet, EMU determines the convenient starting time of the appliance by using Algorithm. The algorithm first checks whether locally generated power is adequate for accommodating the demand. If this is the case, the appliance starts operating, otherwise the algorithm checks if the demand has arrived at a peak hour, based on the requested start time. If the demand corresponds to a peak hour, it is either shifted to off-peak hours or mid-peak hours as long as the waiting time does not exceed maximum, i.e., maximum delay. The computed delay is returned to the consumer as the waiting time. EMU computes the waiting time as the difference between the suggested and requested start time, and sends the waiting time in the START-REP packet to the appliance. The consumer decides whether to start the appliance right away or wait until the assigned timeslot depending on the waiting time. The decision of the consumer is sent back to the EMU with a NOTIFICATION packet that has the same format as the START-REQ packet. The start-time field of the NOTIFICATION packet denotes the negotiated running time of the appliance, i.e., it could be either the time the appliance is turned on or the start time suggested by the EMU. EMU sends an UPDATE-AVAIL packet to the storage unit to update the amount of available energy (unallocated) on the unit. The format of the UPDATE-AVAIL packet is given in Fig. 2(c). The time diagram of the packet flow for the iHEM application is given in Fig. 3. The handshake protocol among the appliance and the EMU ensures that EMU does not force an automated start time. We avoid this approach to increase the comfort of the consumers and to provide more flexibility.

ALGORITHM OF iHEM

STEP 1: Start
STEP 2: Initializes the Zigbee and Devices.
STEP 3: Start the first Protocol to Communicate with Controller.
STEP 4: Get the Input from the Controller.
STEP 5: A) If it is OK GOTO Step 3.
B) If it is NO, Again Initializes the ZigBee.
STEP 6: Start the Second Protocol
P 7: Get the Input from the Controller.
STEP 8: A) If it is OK GOTO Step 6.
B) If it is NO, Check for the Input from Controller.
STEP 9: Stop.

WSHAN to relay the messages of iHEM application since EMU may be physically located far from the appliances, or obstacles may prevent direct communication among appliances and the EMU. Deploying a WSHAN only for energy management could be costly; however, we propose to use the existing WSHAN that is already implemented for monitoring applications in the smart home. The WSHAN can continue its regular task, such as inhabitant health monitoring, and at the same time, it can relay iHEM messages. We show the impact of these underlying applications on the performance of the WSHAN.

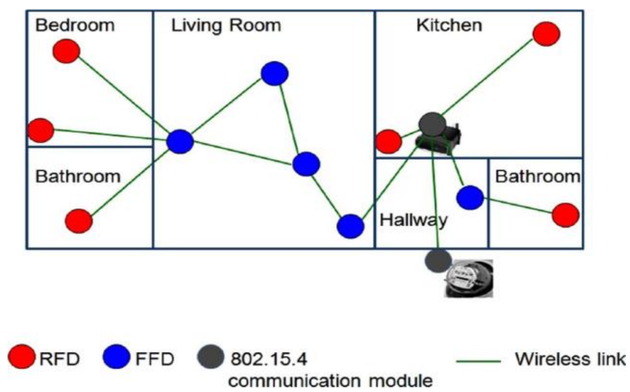

Fig. (4). Smart home communication.

We assume the sensor network implements the Zigbee protocol and we give the network topology in Fig. 4. Zigbee allows two types of devices, which are full function device (FFD) and reduced function device (RFD). FFDs can be interconnected in a mesh topology, which means they can communicate with their peers while RFDs are simpler than FFDs, and they can be the edge nodes in a star topology. In our model home, the WSHAN is organized in a cluster-tree topology where the nodes in the bedroom and bathrooms are RFDs and the nodes in the living room and smart meter are FFDs and EMU is the personal area network (PAN) coordinator. It is possible to designate the smart meter as the PAN coordinator; however, we prefer EMU due to its central position.In iHEM circuit LM7805 power supply series of three terminal positive regulators are available in the TO-220 package and with several fixed output voltages, making them useful in a wide range of applications. Each type employs internal current limiting, thermal shut down and safe operating area protection, making it essentially indestructible. If adequate heat sinking is provided, they can deliver over 1A output current. Although designed primarily as fixed voltage regulators, these devices can be used with external components to obtain adjustable voltages and currents. LM555 timer it is used to control the timing delay through one resistor and one capacitor. The timer is connected to the analog to digital controller (ADC) in the input pin we are connecting the sensors like temperature, pressure. ADC can convert the analog signal digital signal because the microcontroller receives the input as digital signal then the output given to microcontroller AT89C51.Microntroller is used to monitor and control the appliance. If the switch is on then microcontroller controls the information and its transmits the information into serial communication of MAX232 and LCD display.LCD display the power supply taken from battery or grid supply. MAX232 is to for serial communication between storage unit and appliance. The MAX232 is a dual driver/receiver that includes a capacitive voltage generator and voltage levels from a single 5-V supply. In the power management we are using LM7805 voltage regulator it keeps constant output voltage.

V. SIMULATION RESULTS

We use ILOG CPLEX optimization suite to solve OREM of Section IV. For iHEM simulations, we implemented a discrete event simulator in C++. In the first part of this section, we an-alyze the contribution of the appliances to the energy bill and peak load for the OREM scheme, for the iHEM application and for the case when there are no energy management mech-anisms. We evaluate the performance of the WSHAN in terms of delivery ratio, delay, and jitter considering iHEM application with fixed packet size and other smart home applications with varying packet sizes. In the following subsections, we analyze the carbon emission reductions achieved by iHEM. We also ex-tend our simulations to three case studies, first, iHEM with local energy generation, then iHEM with prioritized appliances, and finally, iHEM for real-time pricing.

Residential energy consumption may vary depending on a number of factors such as the size of a house, the number of oc-cupants, the location, and the season. These parameters impact heating, cooling, lighting, and similar loads of the household. In [29], the authors experimentally show that consumption transi-tion can be modeled by a Poisson process which corresponds to switching on an appliance in our case. In our simulations, to model the increasing demand during the peak hours we uti-lize a Poisson process with increasing arrival rate at peak hours. The interarrival times between two requests is negative expo-nentially distributed with a mean of 12 h. During morning peak periods and evening peak periods the interarrival time is nega-tive exponentially distributed with a mean of 2 h. We analyze the use of four appliances; washer, dryer, dish-washer, and coffee maker. The duration and energy consump-tion of these appliances are vendor specific; however, we use the reference values for average load per cycle given in [11]. The washer, dryer, dishwasher, and coffer maker is assumed to consume 0.89 kWh, 2.46 kWh, 1.19 kWh, and 0.4 kWh while the duration of the appliance cycles are given as 30, 60, 90, and 10 min, respectively.

We set the TOU rates as given in Table II while weekends are off-peak periods. The rates are taken as in a typical winter TOU tariff [30]. In OREM scheme, the length of one timeslot is assumed to be 6 h, hence the maximum delay for OREM is set to $D_{\max}=12$ hours. We simulate the schemes from 10 days to 210 days (approximately seven months). We present results as the average of 10 simulation runs.

TABLE I WEEK DAYS TOU RATES FOR WINTER

TOU PERRIOD	*TIME*	*TOU RATE*
ON-PEAK	*6.OOAM-12.00PM*	*9.3 cent/kWh*
MID -PEAK	*12.OOPM-6.00PM*	*8.0 cent/kWh*
ON-PEAK	*6.OOPM-12.00AM*	*9.3 cent/kWh*
OFF-PEAK	*12.OOAM-6.00AM*	*4.4 cent/kWh*

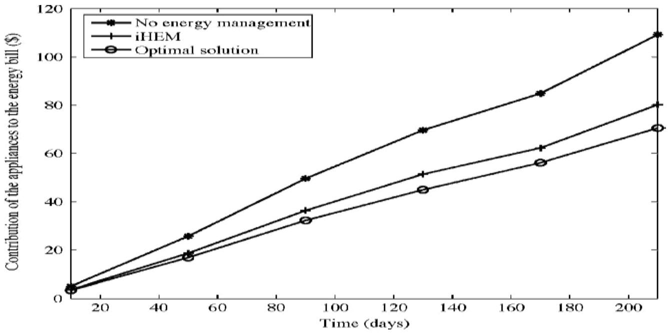

Fig. 5. Total contribution of appliances to the energy bill.

In Fig. 5, we compare the savings of the iHEM application, the optimal solution provided by OREM, and the case with no energy management. Note that total contribution of the appli-ances to the energy bill increases with increasing days because

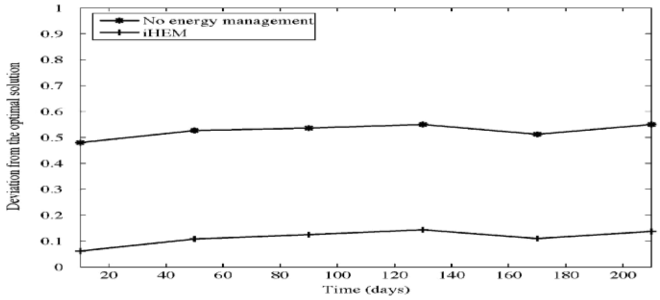

Fig.6.Percentage of deviation from the optimal solution

the bill is calculated cumulatively. As seen in Fig. 5, the iHEM application decreases the contribution of the appliances to the energy bill and the savings of the iHEM application is close to the optimal solution. After 210 days, iHEM scheme results in almost 30% reduction in the energy bill while the optimal solu-tion reduces the bill by around 35%.

In Fig. 6, we give the deviation of the two cases: iHEM and no energy management, from the optimal solution. The deviation from optimal solution when energy management is not used is 0.5, while the deviation of iHEM from the optimal solution is around 0.1. This shows that the iHEM application approaches the savings provided by the OREM scheme. As more appliances opt in the iHEM application, savings are expected to increase as [8] shows that increasing the number of consumer requests increase savings.

In Fig. 7, we present the maximum delay experienced by the consumer. Note that when energy management is not used, i.e., the conventional use of the appliances, an appliance starts as soon as the consumer turns it on and the delay is almost zero. Therefore, we do not include this case in the plot. For the iHEM application, consumers experience a maximum delay around 6 h. In the OREM scheme, demands can be delayed for two times-lots, i.e., 12 h. maker, the consumer will be likely.

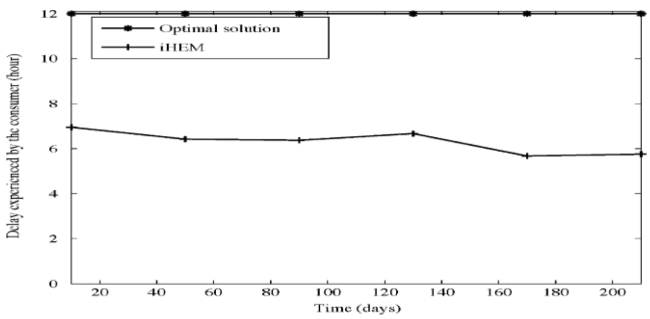

Fig.7. Maximum delay observed by a consumer

to choose to start the appliance immediately. The iHEM appli-cation allows consumers to negotiate or decline to negotiate on the suggested time.We showed that, on the demand side, residential energy man-agement schemes are useful for decreasing energy bills. On the supplier side, reduction in peak load would be another benefit of these schemes. In Fig. 8, we show the contribution of the ap-pliances on the average demand. When energy management is not employed, 0.3 of the load generated by the appliances takes place during peak periods while the iHEM application shifts those requests from peak times and only 0.05 of the total house-hold load is accommodated during peak hours. Therefore, the iHEM application is also capable of reducing the peak demand in the smart grid. We compare the performance of our scheme with the previously proposed schemes that aim to reduce the monthly energy expanses of the consumers. We compare iHEM with RLC [4], DsT [5], and OCS [7] in terms of savings and peak load reduction in Table III. iHEM provides similar savings with DsT and RLC while OCS is able to provide more savings. On the other hand, iHEM outperforms OCS in peak load reduc-tion proportional to average load. In iHEM higher amount of the peak load is shifted to off-peak and mid-peak periods.In our simulations, we evaluate the performance of the WSHAN in terms of packet delivery ratio, end-to-end delay and jitter. Delivery ratio is the ratio of the number of suc-cessfully received packets to the number of sent packets. End-to-end delay is the interval between sending a packet from the application layer of the source and receiving the packet at the application layer of the destination. Jitter is the difference between the delays experienced by the packets.We consider a network topology as described in Fig. 3 where one PAN coordinator is engaged for residential energy manage-ment and other types of WSHAN applications. The nodes are a mixture of RFD and FFD devices, i.e., five FFD devices are used for routing packets and 14 RFD devices, four of which are connected to the appliances are utilized. We use Zigbee protocol utilizing the 2.4 GHz ISM band and the bandwidth is 250 kb/s. Deploying a dedicated WSHAN for relaying iHEM packets is costly; therefore, as we mentioned before, WSHAN relays the packets of iHEM as well as a monitoring application. We show the impact of the varying packet size of the monitoring appli-cation on the overall performance of the network. We vary the packet sizes of this application between 32B and 128B. We assume the nodes generate packets at 10 min intervals. Note that when the packet size exceeds the maximum physical layer packet size defined in IEEE 802.15.4 specifications (128B), it is fragmented to smaller packets.

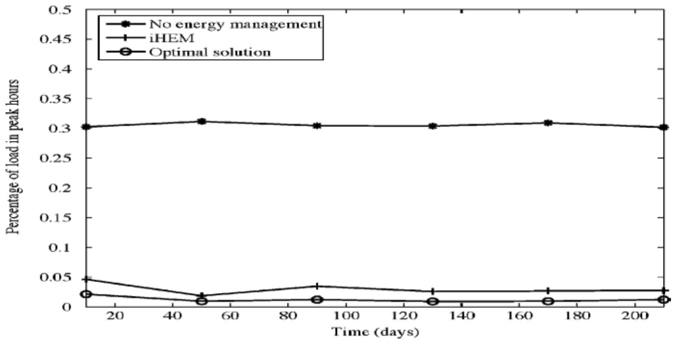

Fig.8. Percentage of the contribution of the appliances to the total load on peak hours.

A. Carbon Emissions for iHEM

Climate change and global warming are considered to be due to the amount of accumulating GHG in the atmosphere; there-fore, reducing carbon emissions is very significant for a sustain-able habitat. Smart grid aims to reduce the CO_2 emissions of the power sector which currently contributes almost 40% of the total emissions [31]. The most effective way of reducing emissions is to mitigate from fossil-fuel based energy generation to renew-able and clean energy resources such as hydro, solar, or wind power. However, the renewable resources are not integrated well to the power grid yet, because of their intermittent nature, lack of storage technology to balance their output, and finally, lack of efficient transportation technologies. Moreover, during peak hours utilities bring peaker plants online which use resources such as diesel or heavy oil, which have high emissions. This im-plies that the time of consumption affects the carbon footprint of the consumers [32].In this section, we focus on the carbon emissions resulting from the electricity consumption of the appliances during peak hours, considering two different regional grids that have dif-ferent energy generation mixes [33]. We assume that Region 1 is geographically rich in renewable resources. We assume the base generation mix is as follows: 50% nuclear, 25% coal and natural gas, 25% hydro, wind, and solar. For peak generation mix we assume: 40% nuclear, 40% diesel and heavy oil, 20% hydro, wind, and solar. For Region 2 we consider a grid where generation mostly depends on fossil fuels. We assume the base generation mix is 30% nuclear, 60% coal and natural gas, 10% hydro, wind, and solar, and peak generation mix is 25% nuclear, 70% diesel and heavy oil, 5% hydro, wind, and solar.

We give the carbon equivalent emissions of the generation resources in Table IV, which are taken from [34]. The emissions related with Region 1 (R1) and Region 2 (R2) are calculated by using the above mixture ratios. In Fig. 10 we show the carbon equiva-lent emissions for R1 and R2 for two cases, namely no energy management (NEM) and iHEM. iHEM can provide 10% to 20% lower emissions depending on the regional characteristics where R1 represents a relatively optimistic scenario with higher pene-tration of renewable resources, and R2 represents a pessimistic scenario with less renewable energy generation penetration.

B. iHEM With Local Power Generation

In the smart grid, energy management for the consumers ex-tends beyond consumption control, and it includes the control of the energy generation of the home. Energy generated at homecan be consumed by the appliances and electronic devices, and the excess energy can be sold to the grid. In this section, we as-sume that the model smart home has three PV panels that are able to generate 350 W per day considering a climate with sev-eral hours of sun light. The rate of electricity sold to the grid depends on the regional grid operator and it is called feed-in tariff (FIT). In Ontario 80.2 cents/kWh is the flat rate for solar generation, and we use this value in our simulations. In Fig.8, we show the savings introduced by the regular iHEM scheme (iHEM w/o feed in) and iHEM with local energy generation (iHEM with feed in). Naturally, iHEM with feed in leads to less expenses because some of the appliance requests can be sup-plied by local resources, furthermore excess energy is sold to the grid. In Fig. 9 we show the daily utilization of local energy resources, the grid, and the amount of energy sold to the grid. Almost 12 kWh of energy is used from the grid, almost 1 kWh is used from the local resources and the remaining is sold to the grid. Note that these results may vary depending on the season,weather conditions, location of the house, and the number and the efficiency of the panels used.

C. iHEM With Priority-Based Scheduling

In this set of simulations, we give priority to a subset of the appliances. High priority appliances are turned on immediately regardless of the peak hours. This scenario corresponds to a case where users have either preconfigured a subset of their appli-ances as high priority appliances or several appliances are not able to communicate with the EMU. The latter case may be more common until smart appliances are widely adopted. In Fig. 9, iHEM w/o priority is the regular iHEM scheme while “iHEM with priority” includes appliances with different priorities. Nat-urally, savings of the consumer reduce when appliances have priorities because this reduces the flexibility of scheduling.

TABLE II COMPARISON OF COST AND PEAK LOAD REDUCTION

	Monthly cost reduction	*Peak load reduction*
iHEM	*30%*	*40%*
RLC[4]	*10%-25%*	*22%*
DST [5]	*16%-25%*	*N/A*
Ocs[7]	*37%*	*38%*

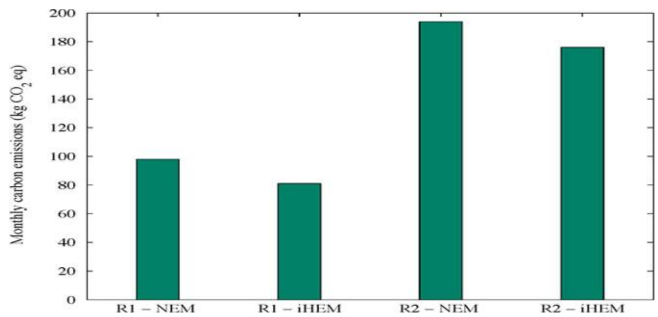

Fig.9. Carbon emissions in two regions with different energy generation mix.

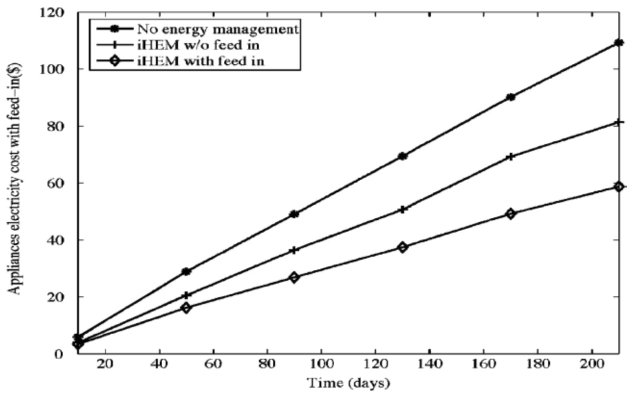

Fig. 10. Appliance electricity usage expenses with local power generation.

D. iHEM With Real-Time Pricing

Throughout the previous sections, we assumed TOU pricing is used in the grid where TOU defines a fixed rate for a cer-tain amount of time. In the smart grid, it is also possible to have real-time (dynamic) pricing. Dynamic pricing reflects the ac-tual price of the electricity in the market to the consumer bills. The market price of electricity is generally determined by the in-dependent system operator where the day-ahead or hour-ahead prices are announced to the consumers. Raw market price of the electricity depends on several factors such as the load fore-casts, supplier bids, and importer bids. The final price is deter-mined after taxes, regulatory charges, transmission and distribu-tion fees, and other service charges are added to the raw market price. In this subsection, we analyze the performance of iHEM for real-time pricing. In Fig. 10, we present the contribution of the appliances for the regular iHEM scheme (iHEM-TOU) and iHEM for real-time pricing. iHEM for real-time pricing still in-troduces savings when compared to the case without any energy management however iHEM performs better with TOU pricing because the scheduling can be coordinated better when the off-peak price stays fixed for a certain amount of time. Scheduling under real-time pricing may require demand prediction in order to increase the performance of scheduling.

VI. CONCLUSION

Residential energy management, smart appliances, WSHANs, and their integration to smart grid applications are becoming popular topics as the governments and the utilitiesare urging for migration to the smart grid. In this paper, we introduce the OREM and the iHEM schemes to reduce the share of the appliances in the energy bills and to reduce their contribution to the peak load. We show that the iHEM application decreases the contribution of the appliances to the energy bill, significantly. We also evaluate the performance of iHEM under various scenarios, which are iHEM with the presence of local energy generation and with real-time pricing.

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