Energy on Demand

Efficient and Versatile Energy Control System for Home Energy Management

Takekazu Kato
Academic Center for Computing and
Media Studies, Kyoto University
Kyoto, Japan
t.kato@ieee.org

Kenji Yuasa
Graduate School of Informatics
Kyoto University
Kyoto, Japan
yuasa@vision.kuee.kyoto-u.ac.jp

Takashi Matsuyama
Graduate School of Informatics
Kyoto University
Kyoto, Japan
tm@i.kyoto-u.ac.jp

***Abstract*—We have been proposing the concept of "*i*-Energy" as a new energy management scheme to realize efficient and versatile control of e-power flows among decentralized energy generation/storage devices and appliances in homes, offices, and neighboring communities. The *i*-Energy concept is best characterized by a novel energy control method named "*Energy on Demand* (EoD)." The novelties of EoD rest in (1) the explicit *demand-based* power supply control, (2) the *best-effort* power distribution based on *appliance priorities*, and (3) the *ceiling control* of power consumption. With EoD, people can attain the *guaranteed* reduction of energy consumption without damaging their quality of lives. Moreover, when utility companies are allowed to set and modify ceiling values based on contracts with consumers, EoD systems work as smart demand response systems. This paper first describes the protocol for EoD: power request demands named "*Quality of Energy* (QoEn)" and appliance priority descriptions. Then, the demand mediation algorithm based on appliance priorities for a single power source is introduced. Experiments using real world everyday-life data in a smart apartment room demonstrated the effectiveness of EoD.**

Keywords-component; Energy Informationization; Energy On Demand; Quality of Energy; Priority Based Power Control; Demand Response

I. INTRODUCTION

Current electrical power networks are designed based on the concept of centralized, unidirectional, and top-down control. The electrical power generated large-scale power plants is distributed to factories, offices, and homes. In recent years, power networks with a large number of distributed generators (e.g., solar powers and wind powers) have been implemented in accordance with policies for the global warming prevention. These distributed power generators are scattered throughout the country, and their electricity outputs are affected by weather and other conditions. Moreover, with the introduction of the electric vehicle, new patterns of demand for electrical power are anticipated. To cope with these new power generation/consumption patterns, it would be difficult to provide stable and efficient power with the traditional top-down centralized control technology. Accordingly, new energy management technology is required to enable the balanced control between supply and demand of electrical power and allow its efficient use. One idea to realize such technology is to introduce the concept of decentralization, bidirectionality, and personalization into power management systems.

Along with such idea, we have been proposing the concept of "energy informationization (*i*-Energy)[1] " as a new energy management scheme to realize efficient and versatile control of e-power flows among decentralized energy generation/storage devices and appliances in homes, offices, and neighboring communities through the holistic integration of information networks and electrical power networks.

The *i*-Energy concept is best characterized by a novel energy control method named "*Energy on Demand* (EoD)" that supplies electrical power based on requests from appliances. That is, 1) when an appliance is switched on, an energy supply *demand message* is issued from the appliance to the energy manager. 2) The manager mediates such demands taking into account available energy sources and *appliance priorities*. This mediation is conducted based on the "*best effort*" policy; some demands with low priorities may not be satisfied. 3) One can set a *ceiling value* for the power supply by the manager; it supplies power only when the ceiling is satisfied. This ceiling control *guarantees* the reduction rate of power consumption.

EoD reduces the total amount of energy consumption by the ceiling control while maintaining the user's quality of life (QoL) through a *best effort* policy of power supply based on appliance priorities. With an EoD system it would be possible to reduce power consumption by 100% (i.e., ignore all requests for power), but that would damage the QoL. It is therefore a key to determine how much power consumption can be reduced while maintaining the QoL. This problem can be solved by studying lifestyle patterns in individual homes and offices and appropriately defining priorities of appliances.

In ordinary smart-grid projects, a demand-response mechanism[1] has been introduced to reduce the demand peak power. When an electricity shortage event is expected in an area, the utility company sends requests to reduce the power consumption to homes, and consumers should then respond accordingly. As is well known, however, it is difficult to keep the power consumption under the requested limit in real time.

With an EoD system, on the other hand, the power consumption can be automatically reduced under the requested limit by setting its ceiling value. That is, when utility companies are allowed to set and modify ceiling values based on contracts with consumers, EoD systems work as smart demand response systems.

978-1-4577-1703-1/11/$26.00 ©2011 IEEE

This paper first describes the protocol for EoD: power request demands named "*Quality of Energy* (QoEn)" and appliance priority descriptions. Then, the demand mediation algorithm based on appliance priorities for a single power source is introduced. Experiments using real world everyday-life data in a smart apartment room demonstrated the effectiveness of EoD.

II. ENERGY ON DEMAND

A. EoD System at Home

In general, the EoD system is a novel electric power management system that intelligently manages power flows among decentralized energy generation/storage devices and appliances in homes, offices, and neighboring communities. This paper addresses the power control method by an EoD system at home, where power is provided to an appliance through the mediation by a home server. 1) When one wants to use an appliance (i.e. switches on the appliance), the appliance sends a "power request message" to the home server first. 2) The home server decides the suppliable power on the basis of the current total power consumption of running appliances, the capacity of the power source(s), and the priority of the appliance. 3) The home server returns a "power allocation or refusal message" to the requesting appliance. 4) Then, the allocated amount of electric power is supplied to the appliance.

With an EoD system, one can set a "*restriction*" value to limit the instantaneously suppliable power to appliances to reduce the peak power. The restriction mechanism enables the real time peak cut to cope with demand response requests from utility companies. Moreover, one can set a "*ceiling*" value to reduce the accumulated electric energy for a period of time, e.g., for a day or a month. The ceiling mechanism guarantees the reduction of the electricity cost and CO_2 emission. The home server manages power supplies to appliances based on their priorities under the restriction and the ceiling.

To optimize the power supply and demand in a home, three types of mediation algorithms are needed. The first is a demand mediation algorithm that controls power flows to appliances taking into account the limitation of the suppliable power. The second is a power supplier mediation algorithm that controls the suppliable power of distributed power generators. The third is a supply-demand matching algorithm that manages electric power flows between power sources and appliances. This paper focuses on the demand mediation algorithm that operates on a single power source network. As the power supplier, we assume utility power supply, since this is the most popular power network in a current household and an office.

B. QoEn appliance model for EoD

The EoD system works with message exchanges between appliances and a home server. An appliance sends a "power request message" to the home server, and receives a "power allocation/refuse message" from the home server. The appliance can be used only if the appliance receives a "power allocation message."

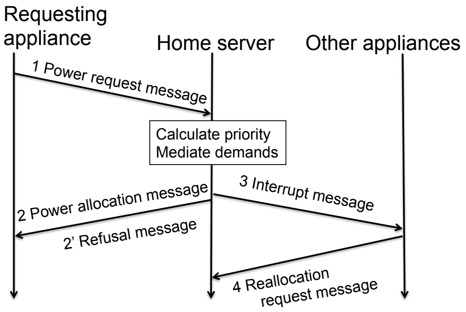

Fig. 1 Demand mediation protocol in EoD.

Table 2 Appliance classes for QoEn.

Class	Power adjustment	Time shiftt	Temporal interruption	Consumer electronics example
I	Yes	Yes	Yes	PC with a battery, charger
II	Yes	Yes	No	Refrigerator
III	Yes	No	Yes	PC without a battery
IV	Yes	No	No	Dryer, lighting
V	No	Yes	Yes	
VI	No	Yes	No	
VII	No	No	Yes	Rice cooker
VIII	No	No	No	Telephone

Table 1 Power request message for EoD.

Property	Value	Remarks
Appliance ID	ID	Identifier
Appliance class	I-VIII	
Requested power	Numerical value(W)	Shared
Minimum startup power	Numerical value(W)	I-IV
Possible interruption time	Numerical value (seconds)	I, III, V, VII
Scheduled startup time	Time	I, II, V, VI
Scheduled operation time	Numerical value(secs)	Option
Priority	0-1	1: top priority
Supply method	AC/DC Voltage	Extension

These messages specify characteristics of power consumption patterns of appliances as well as those of suppliable power patterns by suppliers. We refer to such characteristics of appliances and power supplies as "*Quality of Energy*" (QoEn).

In general, the QoEn can be divided into three categories: the appliance category, which consists of power-demand devices, the power supply category, which consists of power-supply devices, and the power storage category, which consists of devices used for the temporary accumulation of power. In this paper, we address QoEn for the appliance category and the EoD system to conduct the power-demand mediation for single stable power supplier like a utility power line. That is, this paper does not address the power supply category including an unstable power supplier like a solar power generator or the power storage category.

We employ the following three properties to characterize power consumption patterns of devices in the appliance category. That is, the QoEn appliance model is described in terms of the following three properties (see Table 1).

1) Power adjustment capability

For those appliances with this property, the expected function, while not complete, can be achieved even when the supplied power is reduced to a certain degree, e.g. lights, dryers, etc.

Table 3 Power allocation messages for EoD.

Property	Value	Contents
Message type	(for Request) Allocation/refuse (Interruption) suspend/reallocate	Determination of whether to accept or refuse the request. Terminate or reallocate (reduce) power in the case of interruption.
Allocation power	Numerical value (W)	The maximum value of the power that can be supplied, that has been allocated in the case of authorization or reduction
Allocation time	Numerical value (seconds)	The time during which the allocated power can be used (option)
Re-requestable time	Time	The time at which re-request is possible in the case of refusal or termination, or when the allocated power was below the amount requested

2) Time-shift capability

For those appliances with this property, the power supply timing can be shifted without damaging its function, e.g. washing machines, rice cookers, etc. Note that TV does not have this property.

3) Temporal interruption capability

For those appliances with this property, the power supply can be stopped for a short period, e.g. air conditioners, refrigerators, PCs with batteries, etc. Note that a washing machine does not have this property.

With these three properties, Table 2 defines eight appliance classes. Note that those appliances with none of the three capabilities described above can be considered as the most 'rigid' ones for the power supply management by the EoD system.

C. *EoD protocol*

Given all QoEn appliance models in a home or an office, the EoD system conducts the following process to mediate power demand requests and allocate power to appliances based on the best effort policy (see Fig. 1 and Table 3).

1) First, when one switches on an appliance, it sends a “power request message” with QoEn parameters (Table 1) to the home server (1 in Fig. 1). In our experimental system, we attach a "*smart tap*"[3] (see Fig. 8) to each individual appliance, which monitors and controls power consumed by the appliance. The smart tap and the home server exchange messages through the ZigBee wireless network. The "*i-Energy Profile*" defines the communication protocol between them, which includes the QoEn and the EoD protocol described in Tables 1, 2, and 3.
2) The home server uses the currently available power supply and the lifestyle pattern in the home to determine the priority of the appliance that sent the power request. The suppliable power planning and priority determination methods will be given in the next section. Note that one can set the maximally suppliable power (restriction and ceiling values described before), which enables the guaranteed reduction of power consumption.
3) A “power allocation message” (2 in Fig. 1) that includes the allocated power and time allowed (Table 3) is returned to the requesting appliance or a “refusal message” (2’ in Fig. 1) is returned when the suppliable power is limited and the priority of the appliance is low. Note that if the priority of some operating appliance is lower than that of the requesting appliance, an “interrupt message” (3 in Fig. 1) is sent to the lower priority appliance and the power supply to it is stopped or reduced.

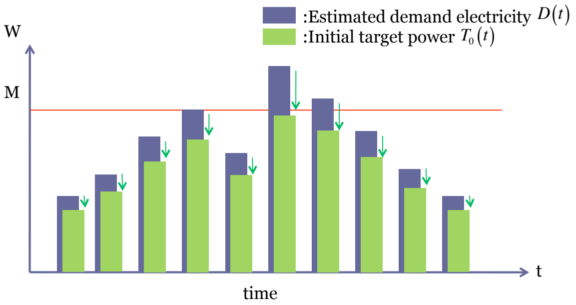

Fig. 2 Estimated power consumption and initial target value profiles.

4) The appliance whose power supply has been authorized operates at the authorized power level for the authorized period. Note that an appliance whose power supply has been refused will send a new request for power allocation after a specified period of time (4 in Fig. 1).

III. DEMAND MEDIATION ALGORITHM FOR THE EOD

In this section, we discuss the algorithm of demand mediation for the EoD protocol. Since the EoD system controls power flows to appliances under the limitation of power consumption based on appliance priorities, we have to define a power usage planning method and an appliance priority model .

A. *Power Usage Planning*

Household electricity demand changes every day and every hour depending on lifestyle pattern, weather, etc., and electricity charges vary seasonally and over time. In the EoD system, a user can set the restriction on the instantaneously suppliable maximum power and the ceiling for total accumulated power. The system should decide the amount of power supply to an appliance as soon as it receives the request power message in real time. Taking these factors into account, we introduce the target value profile for describing dynamically changing expected power consumption . Various methods can be utilized to determine the target value profile. In this paper, we define the target value profile based on the expected power consumption profile learned by monitoring everyday lifestyle in a home with smart taps as well as the user specified restriction and ceiling values.

Here, let M be the restriction value, C the ceiling value of accumulated electric energy for the day, and $D(t)$ the expected power consumption at t estimated from learning data. The initial target profile $T_0(t)$ is defined as follows (Fig. 2):

$$D'(t) = \begin{cases} D(t) & \mathit{if}\ D(t) \leq M \\ M & \text{otherwise} \end{cases}, \quad T_0(t) = \frac{C}{\sum_{i=t_{start}}^{t_{end}} D'(i)} D'(t). \tag{1}$$

This means that the initial target profile $T_0(t)$ is normalized so that it sums up to C and the instantaneous maximally suppliable power is limited by M .

B. Dynamic Model for Appliance Priority Description

When an appliance sends a "request power message," the home server controls the power flow to the appliance depending on its priority. We propose a *dynamic priority model* to control the power flow to the appliance in real time. This is because the priority of an individual appliance should be determined dynamically depending on the appliance properties and user's lifestyle pattern. In this paper, we introduce a fundamental model that only depends on the appliance properties. Note that as discussed in section II.B, appliances are characterized with the three types of control capabilities. We define the dynamic priority function for each capability as follows:

1) Power adjustment capability

Suppose we use a hair dryer. We assume that its user has the most satisfaction with the appliance when the requested power is supplied to the appliance; the lower the power that the appliance is supplied with, the lower the satisfaction of the user. However, even if the supplied power is reduced only slightly, the user satisfaction remains almost unchanged. When the supplied power becomes lower than the minimum power to adequately operate the appliance, the user has the lowest satisfaction. To model these, the priority function for a power-adjustable appliance can be designed as a function of supplied power *p*, $P^a_{\text{adj}}(p)$, as shown in Fig. 4. In this paper, we use the following function as a priority model:

$$P^a_{\text{adj}}(p)=\begin{cases}0 & \text{if } p_{\text{req}}\le p\\ 1-\left(\dfrac{p_{\text{req}}-p}{p_{\text{req}}-p_{\text{min}}}\right)^{\alpha_{\text{adj}}} & \text{if } p_{\text{min}}<p<p_{\text{req}}\\ 1 & \text{if } p\le p_{\text{min}}\end{cases} \qquad (2)$$

where p_{req} and p_{min} are parameters included in a "request power message" from the appliance a : p_{req} denotes the requested power and p_{min} the minimum power to operate the appliance. α_{adj} is a parameter to determine the decline of the power-priority curve.

2) Time-shift capability

The power supply starting time of a time-shiftable appliance can be delayed from a requested time. For such an appliance, a user wants to finish the work by the appliance before a specified time: finish washing before noon. To model these, the priority function for a time-shiftable appliance can be defined as a function of time *t*, $P^a_{\text{shift}}(t)$, as shown in Fig. 3. In this paper, we use the following function:

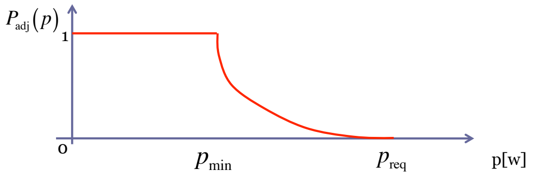

Fig. 4 Priority function for a power-adjustable appliance.

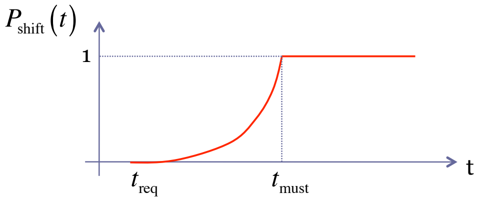

Fig. 3 Priority function for a time-shiftable appliance.

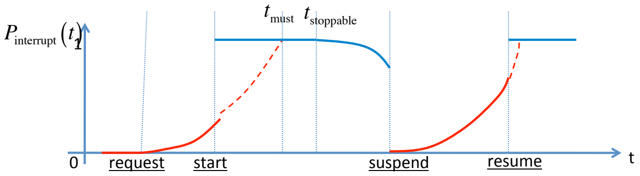

Fig. 5 Priority function for a temporary interruptable appliance.

$$P^a{}_{\text{shift}}(t)=\begin{cases}1-\left(\dfrac{t_{\text{req}}-t}{t_{\text{must}}-t_{\text{req}}}\right)^{\alpha_{\text{shift}}} & t\le t_{\text{must}}\\ 1 & t>t_{\text{must}}\end{cases}. \qquad (3)$$

where t_{req} denotes the time that the user makes a power request and t_{must} the time when the appliance must be started at the latest.

3) Temporary interrupt capability

Power supplies to temporarily interruptable appliances, e.g., air conditioners, heaters, etc., can be suspended during their operation periods because they have some buffering functions. Since the buffers are limited, their utilities decrease when suspended for a long time. Thus, the priority function for a temporarily interruptable appliance can be designed with two modes as shown in Fig. 5.

$$P^a_{\text{interrupt}}(t)=\begin{cases}P^a_{\text{running}}(t) & \text{if } a \text{ is running}\\ P^a_{\text{suspended}}(t) & \text{if } a \text{ is suspended}\end{cases} \qquad (4)$$

where $P^a_{\text{suspended}}(t)$ can be defined in a similar fashion to the priority function of a time-shiftable appliance as follows:

$$P^a_{\text{suspended}}(p)=\begin{cases}1-\left(\dfrac{t_{\text{suspend}}-t}{t_{\text{must}}-t_{\text{suspend}}}\right)^{\alpha_{\text{suspended}}} & t\le t_{\text{must}}\\ 1 & t>t_{\text{must}}\end{cases}, \qquad (5)$$

$$P^a_{\text{running}}(p)=\begin{cases}\left(\dfrac{t_{\text{stoppable}}-t}{t-t_{\text{stoppable}}}\right)^{\alpha_{\text{running}}} & t \le t_{\text{stoppable}} \\ 0 & t > t_{\text{stoppable}}\end{cases} \tag{6}$$

4) Priority Functions for Appliance Classes

As illustrated in Table 1, appliances are classified into eight classes based on the three capabilities. Thus we have to define the priority functions for the eight appliance classes by combining the priority functions given above: $P^a_{\text{adj}}(p)$, $P^a_{\text{shift}}(t)$, and $P^a_{\text{interrupt}}(t)$. We define the priority function of appliance *a* in class I with all three capabilities, $P^a_I(p,t)$, as follows:

$$P^a_I(p,t)=\begin{cases}P^a_{\text{adj}}(p)P^a_{\text{shift}}(t) & \text{before start} \\ P^a_{\text{adj}}(p)P^a_{\text{interrupt}}(t) & \text{running/suspended}\end{cases}. \tag{7}$$

If the appliance does not have a capability, the priority function for the capability is set to constant value 1. Therefore, the priority functions for classes II-VII can be derived by eliminating from equation (7) either of $P^a_{\text{adj}}(p)$, $P^a_{\text{shift}}(t)$, or $P^a_{\text{interrupt}}(t)$. The priority function of class VIII is defined as $P^a_{VIII}(p,t)=1$.

C. Demand mediation algorithm

The EoD system reduces the power supply to an appliance with a low priority to comply with the power reduction requirements specified by the restriction and ceiling values. Priority values of appliances, as described in the previous section, change dynamically according to their priority functions. Thus, the demand mediation algorithm of the EoD system should be designed taking these features into account.

To comply with the two types of limitations, the maximum demand power and the ceiling of accumulated energy consumption, against dynamically changing energy consumption patterns of appliances, we developed the demand mediation algorithm consisting of three parallel control processes, 1) event-driven process, 2) periodical process and 3) continuous process.

0) Initialize

Calculate the initial target value profile $T_0(t)$ based on expected power consumption $D(t)$, the restriction value M, and the ceiling value C. As defined by equation (1), $T_0(t)$ satisfies

$$\sum T_0(t) \le C, \quad \max T_0(t) < M. \tag{8}$$

Set the current target value profile $T_1(t) := T_0(t)$ and $i := 1$.

The home server always calculates the total power consumption $E_{\text{total}}(t_{\text{now}})$ of running appliances $a \in A_{\text{available}}$ and priority $P^a(E_a(t_{\text{now}}),t_{\text{now}})$ at current time t_{now}.

$$E_{\text{total}}(t_{\text{now}})=\sum_{a\in A_{\text{available}}} E_a(t_{\text{now}}). \tag{9}$$

where E_a denotes the power consumption of appliance *a*.

1) Event-driven process

The event-driven is a basic process to madiate requests from the appliances. When the home server recieves a "power request message" with requested power E_{req} from appliance a_{req}, the home server starts mediation as follows:

[Step 1a.] Calculate the total power consumption $E_{\text{total}}(t_{\text{now}})$ and priority $P^a(E_a(t_{\text{now}}),t_{\text{now}})$ for available appliances at current time t_{now}.

[Step 1b.] If $E_{\text{total}}(t_{\text{now}})+E_{\text{req}} < T_i(t_{\text{now}})$, then the server sends a "power allocation message" to a_{req} and finish the process, otherwize go to next step.

[Step 1c.] If $\min\limits_{a\in A_{\text{available}}\cap A_{interrupt}} P^a(E_a(t),t) < P^{a_{\text{req}}}(E_{\text{req}},t)$, the server sends to $a_{\min} = \operatorname*{argmin}\limits_{a\in A_{\text{available}}\cap A_{interrupt}} P^a(E_a(t),t)$ an "interrupt message" and repeat from Step 1a, otherwise go to next step.

[Step 1d.] The server sends a "refuse message" (if a_{req} does not have any power adjustment capability) or a "power reduction message" with power allocation $T_i(t)-E_{\text{total}}(t)$ (if a_{req} has power adjustment capability) and finish the process.

2) Periodical process

The home server starts the periodical process for each time interval τ. The server updates the target value profile described in section III.A to cope with dynamically changing human-requests and priority values as well as the specified power limitations.

[Step 2a.] Update the target value profile as follows:

$$T_{i+1}(t) := \min\left(\gamma\left(\hat{T}_i(t_{\text{now}})-\hat{E}(t_{\text{now}}),t-t_{\text{now}}\right)T_i(t), M\right), \tag{11}$$
$$\hat{E}(t_{\text{now}})=\sum_{x=t_{\text{start}}}^{t_{\text{now}}} E_{\text{total}}(x), \quad \hat{T}_i(t_{\text{now}})=\sum_{x=t_{\text{start}}}^{t} T_i(x)$$

Here, $E_{\text{total}}(t)$ is the actual power consumption and $\gamma(X,t-t_i)$ is the gap distributed function.

Set $i := i+1$ and go to next step.

[Step 2b.] If $E_{\text{total}}(t_{\text{now}}) > T_i(t_{\text{now}})$, the server finds appliance $a_{\min}$ with the minimum priority with temporary interrupt capability or power adjustment capability. The home server sends an "interrupt message" or a "power reduction message" to $a_{\min}$.

$$a_{\min} = \underset{a \in A'_{\text{available}}}{\operatorname{argmin}} P^{a}\left(E_a\left(t_{\text{now}}\right), t_{\text{now}}\right) \tag{10}$$

Here, $A'_{\text{available}}$ is a set of appliances with temporary interrupt or adjustment capabilities in $A_{\text{available}}$.

And repeat this step while $E_{\text{total}}\left(t_{\text{now}}\right) > T_i\left(t_{\text{now}}\right)$, otherwise finish the process.

3) *Continuous process*

The continuous process continuously watches the total power consumption $E_{\text{total}}\left(t_{\text{now}}\right)$ to keep it under the maximum demand power M .

[Step 3a.] If $E_{\text{total}}\left(t_{\text{now}}\right) > M$, the server finds appliance $a_{\min}$ with the minimum priority with temporary interrupt capability or power adjustment capability. The home server sends an "interrupt message" or a "power reduction message" to $a_{\min}$. And repeats step 3a.

The algorithm works by combination of three parallel processes, event-driven, periodical and continuous process. The server mediates the power request message from appliance as soon as receives by event-driven process. On the other hand, the target value profile is updated at regular intervals τ to achieve the amount of power consumption under the ceiling C by the periodical process. The server watches the total power consumption to keep it under the maximum power consumption M by continuous process.

IV. EXPERIMENTS

A. *Experimental Environments*

We developed a smart apartment room equipped with smart taps[3] (Fig. 8) to demonstrate life-pattern monitoring and electricity consumption visualization[4]. The room includes 19 appliances attached with smart taps (lights, a TV, DVD player, electric cooker, air conditioner, hair dryer, etc). Five people lived in the room (three days per person) to collect power consumption patterns in real world life.

We conducted simulation experiments using the collected data, where we assume a person in the room controls the appliances as specified in the collected data and the EoD system virtually controls the appliances to comply with the restriction and the ceiling.

The target value profile $T_0(t)$ is calculated by equation (1) , where the expected power consumption at *t*, $D(t)$, is obtained by the moving average of the collected data. We set the restriction value M , 1200 W and the ceiling value C , 30% less than the collected data.

B. *Experimental Results*

The experimental results for a day of a university student are shown in Fig. 6 and 7: the former illustrates the instantaneous power consumption profile and the latter the accumulated one. The blue lines indicate real world life data without the EoD system collected in the smart apartment room, the red the initial target value profile $T_0(t)$ and its integrated version $\sum_{\tau=0}^{t} T_0(\tau)$, and the green the results of the power management by the EoD system. It is proved that the power consumption of the appliances is well controlled according to the target value profile, keeping the everyday life style as well as complying with the restriction M and the ceiling C.

V. CONCLUSION

In this paper, we proposed a novel home energy management method named "*Energy on Demand*" with (1) the explicit *demand-based* power supply control, (2) the *best-effort* power distribution based on *appliance priorities*, and (3) the *ceiling control* of power consumption. Experimental results proved that with EoD, people can attain the *guaranteed* reduction of energy consumption without damaging their quality of lives.

Currently we are developing a real world EoD system in the smart apartment room, whose experimental results will be given at the conference presentation.

ACKNOWLEDGEMENT

This work was partialy supported by Grant-in-Aid for Scientific Research 23700169.

REFERENCES

[1] T. Matsuyama: Creating Safe, Secure, and Environment-Friendly Lifestyles through i-Energy, New Breeze, Vol. 21, No. 2, pp.1-8, 2009.4.

[2] NIST, "Smart Grid Home Page," http://www.nist.gov/smartgrid/.

[3] T. Kato, H. Cho, D. Lee, T. Toyomura, and T. Yamazaki. Appliance Recognition from Electric Current Signals for Information-Energy Integrated Network in Home Environments. International Journal of Assistive Robotics and Systems (IJARS), Vol. 10, No. 4, pp. 51-60, (2009).

[4] "Eco-life in a Smart Apartment room with an integrated Smart Tap Network," http://www.i-energy.jp/data/Smart-Apartment2010-09.pdf, 2011.

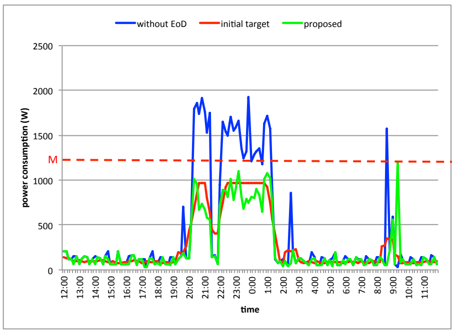

Fig. 6 Power consumption profile

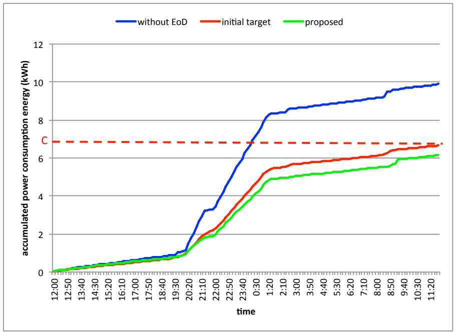

Fig. 7 Accumulated power consumption energy.