Methodologies for Effective Demand Response Messaging

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***Abstract*—Demand Response (DR) is considered an effective mechanism by utilities worldwide to address demand supply mismatch and reduce energy consumption, peak load and emissions. Consumer participation is central to realize the full potential offered by DR programs. The communication between a utility company and consumers participating in DR is through *DR messages*. However, despite the importance of DR messages in the context of residential DR programs, only a limited number of relevant experimental studies have been reported in literature so far. To address this gap, in this paper, we report findings from 6-month long DR field trials involving residential participants in Luleå, Sweden. The trials specifically focus on four aspects related to DR messages - notification mechanism, message type, associated incentive, and participation feedback. The primary outcome of these trials is a set of guidelines and recommendations for design of effective DR programs.**

Keywords—Demand Response, User participation, Field Trial, DR messages

I. Introduction

Global consumption of water and energy has been increasing rapidly over the past decades, and both resources are in short supply. While increased supply is one solution to this problem, this cannot always be done fast enough to meet demand, and some resources (such as fossil fuels and groundwater) cannot be replaced as they cannot be quickly replenished. Demand management is considered to be a more effective solution to address the supply demand mismatch. In this context, energy utility companies across the world are becoming increasingly interested in demand response (DR) programs, wherein consumers willfully agree to reduce their energy consumption in return for an appropriate incentive [1].

Energy consumption by the residential sector accounts for around 18% of the total worldwide energy consumption [2]. Therefore, this sector represents an important target set with regard to demand curtailment programs such as DR. There are several factors influencing the impact of DR programs in the residential domain that need to be considered for DR planning and execution. Examples of these factors include, but are not limited to demographic parameters and geographical location of the target consumers, time of DR, type of DR signals sent, type of incentives (if any), communication mechanism employed to notify the consumer regarding a DR event, etc. The impact that these factors have on the underlying DR objectives such as peak demand reduction and total demand reduction is non-trivial to understand. Since the main premise of DR is user participation, experimental studies involving real users are required to better understand the impact of these factors. Such studies can help utility companies interested in DR to design effective DR programs, with an aim to satisfactorily achieve underlying objectives.

The communication between a utility company and consumers participating in DR is through *DR messages*. Therefore, the role of DR message is central in influencing the user to participate, and hence in achieving the desired goal of reduction in energy demand. However, despite the importance of DR messages in the context of residential DR programs, only a limited number of relevant experimental studies have been reported in literature so far. To address this gap, we undertook 6-month long detailed DR field trials involving residential participants in Luleå, Sweden, findings from which are presented in this paper. The field trials specifically focus on four aspects related to DR messages - notification mechanism, message type, associated incentive, and participation feedback. During the course of these trials, various DR messages were sent by varying these aspects so as to study their impact in detail. Additionally, these experiments were complemented with user interviews for a more holistic assessment. Upon conclusion of the field trials, the results were analyzed in detail to derive important guidelines and recommendations which can be used by utility companies to improve the impact of their DR programs by incorporating well designed, effective DR messaging aspects.

The field trials reported in this paper are a first of its kind investigation into aspects related to DR communication, both in terms of scope and scale. The primary contribution of this paper, therefore, is a set of guidelines and recommendations obtained through scientifically conducted field studies. Some of the key recommendations and best practices identified from these trials are as follows:

1. Display of real-time consumption data, with continuous update to show the effect after a DR event has been acted upon, is important to the consumer.
2. Monetary incentives should be employed in DR, since they are more effective than other types of incentives in

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inducing consumers to participate in DR. In particular, a lottery mechanism offering higher rewards is more attractive than a low yet certain reward.

3. A combination of incentives with the automation of the processes at users' premises is likely to have the maximum impact

The organization of this paper is as follows. Related work is presented in Section II. Section III provides details of the system architecture that was implemented to conduct the DR trials reported in this paper. Details of the experiments conducted are presented in Section IV. Section V contains results from the experiments and their analysis to derive important guidelines and recommendations in the context of DR messaging. Conclusions are presented in Section VI.

II. RELATED WORK

In this section we discuss related work in the area of field deployments of demand response systems. Various studies have emphasized that DR can be an effective mechanism for addressing the challenges of growing energy demand and related supply-demand imbalances [3-5]. A report by US Federal Energy Regulatory Commission [6] estimates that full participation in DR can result in up to 20% reduction in peak demand. It has also been estimated [7] that DR programs alone could achieve up to half of the European Union's 2020 targets related to energy savings and CO2 emissions.

Field trials in the area of DR have however, mostly focused on the impact of pricing on DR potential. For example, in 2003, NYISO paid out incentives to around 14,000 consumers to reduce peak demand by 700 MW, which translated into savings of 7 times compared to the cost of the program [8]. In particular, several studies have been undertaken by utility providers all around the world to understand the impact of Time of Use (TOU) pricing on peak demand reduction. Examples include Electricite de France and Gulf Power Company [9]. However, most of these programs focus on industrial and commercial consumers.

A holistic evaluation of DR, which includes an analysis of various other influencing factors besides the price of energy, is needed to drive coordinated DR policies [10] in Europe and other geographies. In [11], the authors propose iDR: an inclusive DR system which selects consumers for DR based on inconvenience caused due to reduction or change in energy consumption behavior. However, it assumes that participation probabilities of consumers in a DR program are known. In reality, the participation of consumers can be a function of several influencing contextual factors, which need to be considered.

To summarize, despite an awareness of the "huge" potential of DR in the residential domain [8, 12], there is a lack of field trials that perform a holistic assessment of the factors influencing participation of residential consumers in DR programs. Since sufficient user participation is key for realizing the above stated potential of DR in providing peak reduction, energy efficiency and emissions related benefits, the central theme of our work is to understand and quantify the influence of factors beyond energy price on users' decisions and actions, so as to design more effective DR messages for residential consumers.

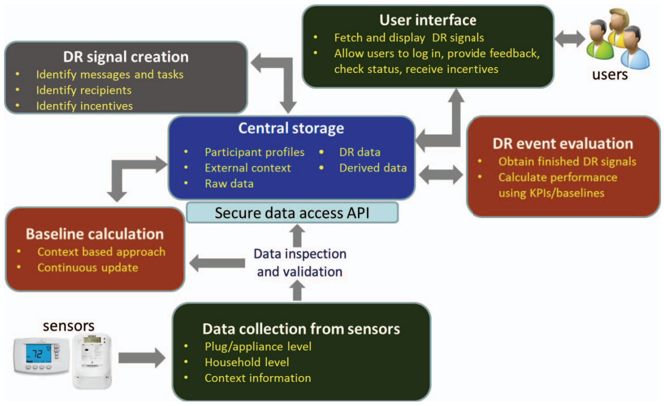

Figure 1. DR message system overview

III. SYSTEM DESIGN

An overview of the DR system implemented in the field trials with the underlying components and the interconnectivity between them is shown in Figure 1. The corresponding semantics is explained below. Firstly, baseline energy consumption is computed based on an analysis of sensor data collected over an appropriate time window. Comparative analysis of the baseline consumption with real time consumption, together with an analysis of the relevant contextual data - such as temperature, energy prices, time of the day, etc. - is then undertaken to determine appropriate DR signals. This consists of identifying certain attributes associated with a DR event such as DR messages and tasks, recipients and incentives. The DR events are then implemented via user interfaces. Once a DR event has been executed, its effectiveness is evaluated using appropriate Key Performance Indicators (KPIs). A DR designer dashboard is used to monitor ongoing and past DR events. It is to be noted that as shown in Figure 1, all of the above mentioned processes are carried out by either extracting relevant data from, or writing relevant data to, a central storage system.

A. Data Collection From Sensors

In the DR system, consumption data at plug/appliance level and household/building meter level is collected using appropriate sensors. In addition, context data is also collected. All data is then stored in the central storage after inspection and validation.

B. Baseline Calculation

The baseline consumption calculation is based on the context based baseline estimation method presented in [11]. The calculations are performed and updated on a continuous basis. Upon computation, the baselines are sent to the central storage.

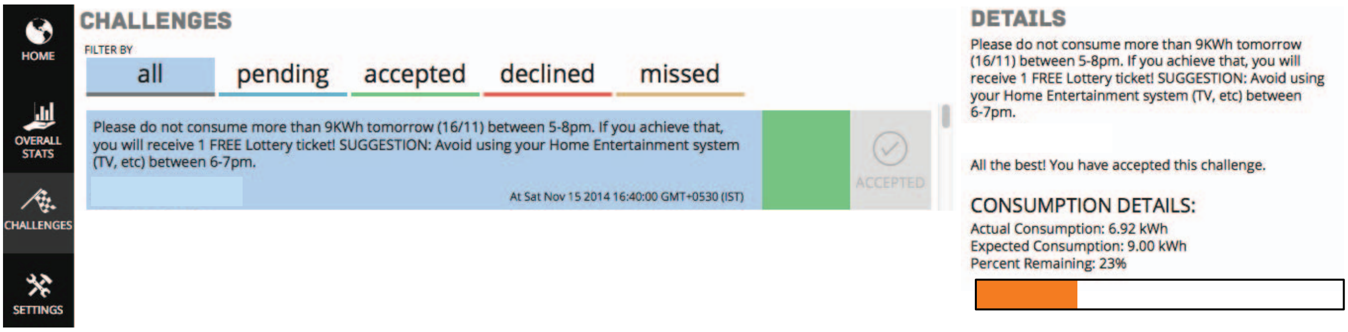

Figure 2. User Interface

C. DR Signal Creation

Appropriate DR signals are created based on a consideration of underlying contextual factors. The process identifies messages and tasks, and recipients and incentives. Once the DR signals are created, they are sent to the central storage.

D. User Interface

Interactive user interfaces are designed and used to fetch and display DR signals. These interfaces are "user-centric" and allow users to log in, provide feedback, check status, and receive incentives (Figure 2). The interface interacts with the central storage on one side and the users/DR participants on the other side.

E. DR Event Evaluation

DR event evaluation is performed based on finished/executed DR signals. This information is obtained from the central storage. In the evaluation process, completed DR signals are fetched, and their performance is quantified by computing appropriate KPIs (e.g. energy consumption reduction from baseline).

F. Central Storage

A central storage system is the "hub" component, which interacts with all of the above-mentioned components. The system stores data on participant profiles, external context, raw data, DR data and derived data. In addition, a secure data access API is provided for data access.

IV. Field Trials

In this section, we provide an overview of the field trials that were conducted at the Luleå (Sweden) trial site. We studied the impact of different factors - including incentive and DR message notification type - on the acceptance of DR messages and the resultant energy savings.

We conducted a 6-month long field trial. During the trial period, three DR messages were delivered to each participant, every week (two of them over weekdays, and one over weekend). All the DR messages targeted reducing consumption during morning hours of 6-8 am. The messages were delivered a day in advance (7-8 pm). For each message, a participant can 'accept' or 'decline' a message on the user interface. A reminder message was delivered in the morning of the event, if the participant accepted the DR message.

The objective of the field trial is to understand the impact of four factors on DR messages – notification, message type, incentive, and feedback. For each factor, we compared two design choices, which were selected based on literature and our discussion with utility managers. Each factor was deployed for 6 weeks, with each design choice being deployed for 3 weeks. Hence for a particular design factor choice, each of the 10 participants received 9 DR messages. To counterbalance the order effect, the 10 participants were randomly divided in two groups – Group A and Group B, comprising of 5 participants each. For the initial 3 weeks of a factor study, Group A received the first design choice and Group B received the second design choice. After the three weeks, the design choices were switched between Group A and Group B. This ensured that memory effect does not affect our results. Moreover, for each factor study trial, five participants for Group A and B were chosen randomly, from the 10 participants. This was done to counter any group effect.

Based on the outcome from 6-weeks data, one of the design choices is chosen for the rest of the field trial. Apart from the DR message experiments, we conducted four user meetings at the end of every sixth-week, to get qualitative feedback on the design choices.

Each of the four factors with their design choices is described in detail in this section:

A. DR Message Notification: Individual (SMS) vs Family (Wall Display)

There are different ways to deliver DR messages at a residential setting. The messages can be targeted to an individual or can be sent to the full family to act upon. We compared two notification types: (a) sending messages to an individual resident (the '*householder*', as described below) of the house in the form of SMS, versus (b) installing a tablet-based wall display in the house which provided access to the DR message to all the family members. The tablets were installed on the wall of the living room, as it is accessible by all family members. On delivery of a message, the tablet used to beep and play a notification sound.

Table 1. Participants Demography

PId	Sex	Age	Marital Status	Education	Occupation	Income	Leave Home	Return Home	Internet-Savvy	Adult	Children	Room	Bath-rooms	Conservation
1	F	47	Married	Masters	Education	400,001-800,000 SEK	7-8 am	4-5 pm	4	3	1	8	2	4
2	M	37	With Partner	High School	Software	400,001-800,000 SEK	7-8 am	4-5 pm	5	2	2	6	2	3
3	M	45	Married	Bachelors	Software	800,001-1,500,000 SEK	7-8 am	7-8 pm	3	4	0	5	2	4
4	M	45	Married	Bachelors	Hardware	400,001-800,000 SEK	7-8 am	7-8 pm	3	3	1	5	1	3
5	M	47	Married	High School	Software	400,001-800,000 SEK	7-8 am	4-5 pm	5	3	1	5	2	4
6	M	48	With Partner	High School	Software	400,001-800,000 SEK	7-8 am	5-6 pm	5	2	3	8	3	4
7	M	41	Divorced	Bachelors	Hardware	400,001-800,000 SEK	7-8 am	5-6 pm	5	2	2	5	2	4
8	M	42	Married	Bachelors	Self-employed	400,001-800,000 SEK	7-8 am	5-6 pm	5	2	1	5	2	4
9	M	46	With Partner	High School	Self-employed	400,001-800,000 SEK	7-8 am	5-6 pm	5	3	1	5	2	3
10	M	38	Married	PhD	Hardware	800,001-1,500,000 SEK	9-10 am	5-6 pm	5	2	1	5	2	3

B. *DR Message type: Simple vs Specific*

DR messages can be highly simple, e.g., '*Reduce your energy consumption during 6-8 am tomorrow (16/11)*', or it can be highly specific, e.g., '*Reduce your energy consumption to 5 kWh during 6-8 am tomorrow (16/11) by switching off TV and avoid using your washing machine.*' Both forms of DR messages have its merits and demerits. Simple DR messages might motivate people to reduce even lower than expected and also in more interesting ways. However, it can also lead to confusion, as residents might not be aware how to reduce energy consumption. On the other hand, specific DR messages might limit the energy reduction, but provides a clear idea to the participant of what needs to be done to achieve the goal.

C. *Incentive: Fixed vs Lottery*

Previous work in sustainability has indicated that incentives result in higher participation and higher energy savings [13]. Moreover, previous work in Economics [14] showed that bigger lottery-based incentive performs better than smaller fixed incentive. Hence in our trial we compared lottery-based incentive in the form of four movie tickets to one of the homes achieving the target mentioned in the DR message, versus fixed incentive in the form of a free coffee coupon.

D. *DR Message Feedback: Not real-time vs Real-time*

Initially, we did not provided any real-time feedback for the ongoing DR message, in terms of how much target is achieved. Based on the feedback obtained from the participants during qualitative feedback sessions, we added statistics showing the status of the ongoing DR message task. A battery icon was added showing the amount of energy left that can be used during the time period referred in the DR message. Hence at the end of the DR message time period, the battery status should be higher than 1% to achieve the target specified in the DR message.

We asked the "householder" to provide demography data. The "householder" refers to '*the person (or one of the people) in whose name the housing unit is owned or rented (maintained) or, if there is no such person, any adult member, excluding roomers, boarders, or paid employees. If the house is owned or rented jointly by a married couple, the householder may be either the husband or the wife.*' The householder is our point of contact for the field trial, and hence also referred as the *participant*.

E. *Demography Details*

Ten residential homes in Lulea (Sweden) participated in the field trials, during the year 2013-14. Each of the houses was a bungalow, with five to eight rooms (mean = 5.7, standard deviation = 1.3), and one to three bathrooms (m=2, stdev=0.5). In each house, two to four adults (m=2.6, stdev=0.7) were living with 0-3 children (m=1.3, stdev=0.8). The household income was above Swedish average income [15] with eight of them reported earning 400,001-800,000 SEK per year, and two reported above 800,000 SEK per year.

Participants comprise of 1 female (9 male), with an average age of 43.6 years (stdev=3.9). All, except one, used to leave their home for office at 7-8 am, while time to return back home varied with 5 participants returning at 5-6 pm, 3 at 4-5 pm, and 2 at 7-8 pm. This shows that on an average, participants spent 10 hours outside their home. The education level of the participants was evenly distributed with 4 completed high school, 4 completed Bachelors, and 1 each completed Masters and PhD. Majority of the participants (6) were married, while 3 were living with their partners and 1 was divorced. All the participants were working full-time, with 4 working in the software industry, 3 in the hardware industry, 1 in the education sector, and 2 were self-employed. All participants were responsible for paying their own electricity bills. All the participants answered in neutral to strongly agree (on a 5-point Likert scale) when asked about their orientation towards conservation, "*I am environment-friendly and do everything possible to save the environment?*" Table 1 provides key demographic data about our participants.

V. RESULT

The data revealed a high acceptance rate of 41.1% per message (7.3% declined, and 51.6% not answered), with average energy savings of 2.7 kWh (sd=2.8) per message per household.

As discussed previously, for a particular design factor choice, each of the 10 participants received 9 DR messages. Hence for each of the four factors, the two design choices are compared using the data obtained from 90 DR messages for each design choices. We computed mean, standard deviation, and compared the data using t-test to find significant differences with respect to acceptance of the DR message, completing the DR task mentioned in the DR message, and respective energy savings.

Acceptance rate was calculated using percentage of DR messages being accepted by the participant by clicking the '*Accept*' button on the user interface. Out of the total accepted messages*, acted rate* was percentage of DR messages in which the task mentioned in the message was completed. Figure 2 provides an overview of acceptance and acted rate for all the design choices. For each accepted message, *energy savings* was calculated by subtracting the actual energy consumption with the baseline consumption (baseline calculation has been discussed in prior section).

A. DR Message Notification: Individual (SMS) vs Family (Wall Display)

Analyzing the data revealed that acceptance rate was higher for Individual (SMS), while acted rate and energy savings was higher for Family (wall display). The acceptance rate was 65.6% (14.4% declined and 20% not answered) with SMS, while 43.3% (7.8% declined and 48.9% not answered) with wall display. This may be due to the fact that the person receiving the SMS is responsible for accepting/declining the message, while at home, family members might delegate such responsibilities, or no one wants to take the ownership. Out of the total accepted messages, 50.8% acted upon and completed the DR task in the individual SMS condition, while 64.1% completed in the family wall display condition. With respect to energy savings, participants in the family display (m=2.72, sd=3.27) performed better than the individual SMS condition (m=2.56, sd=3.21). This may be because all the family members are aware and can contribute to the energy savings. However we did not find any statistical significant energy savings differences, with t_{96}=1.2, p=0.08. During the qualitative interview, the participants complained of "*infringing privacy*" with the SMS based system. The level of privacy intrusion varies across regions [16] with developed nations being more privacy intolerant compared to developing regions, hence in other demography, an SMS based system may find more acceptance among the participants. Moreover, participants were of the opinion that the whole family involvement is necessary, more importantly the "*children should learn energy conservation*" too, hence a wall display for the whole family is a better solution. As we did not have a clear winner among the two design choices, for future DR messages, we used a hybrid with wall display showing delivered DR messages, while a new message arrival notification was delivered as SMSes to participants who have registered for the SMS service.

B. DR Message type: Simple vs Specific

Data showed that Specific DR messages outperformed Simple DR message. With respect to acceptance rate, 42.2% of Simple messages were accepted (8.9% declined, 48.9% not answered), while 57.8% of the Specific DR messages were accepted (0% declined, 42.2% not answered). This may be because participants were more confident in accepting DR messages with clear specific ways to achieve the goal. More

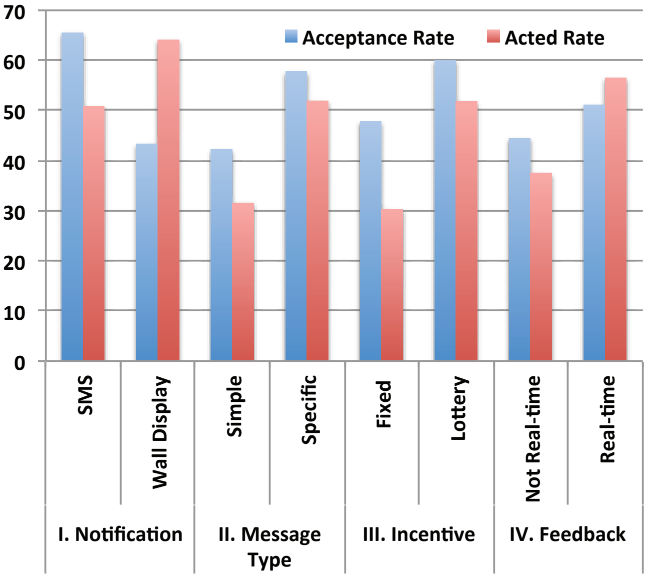

Figure 3. Results: Acceptance and Acted Rate

interestingly, out of the accepted messages, 51.9% of Specific messages were completed by the participants, compared to 31.6% of Simple messages. This shows that participants, not only accepted, but also completed higher number of Specific DR messages. During the interviews also, for Simple messages, participants asked the interviewers on ways to reduce energy consumption. On the other hand, participants praised Specific DR messages, as they are "*easier to understand*" and "*provides clear instructions on how to achieve the mentioned task*". Finally, on an average, Simple DR messages achieved 1.76 kWh (sd=2.16) of energy savings per message, while Specific DR messages achieved 5.1 kWh (sd=4.36). Student's t-test showed that Specific messages is statistically better than Simple messages, with t_{88}=6.7, p<0.01. Thus for the rest of the field trials, we chose to deliver Specific DR messages.

C. Incentive: Fixed vs Lottery

We found that lottery based incentive outperformed fixed incentive. With respect to acceptance rate, 47.8% of fixed incentive DR messages got accepted (6.7% declined and 45.5% unanswered), while 60% of lottery incentive based messages were accepted (6.7% declined and 33.3% not answered). Moreover, even higher number of messages task were completed in lottery based messages, with acted rate of 51.8%, compared to 30.2% for messages with fixed incentives. This confirms with previous findings in behavioral economics [14] that lottery system acts as a bigger motivator for participants compared to fixed incentive system. In terms of energy savings, lottery based messages (m=3.6, sd=3.9) outperformed fixed messages (m=1.15, sd=1.2), with t_{95}=5.3, p<0.05. Even during the interview, the participants were excited about the winner of the lottery movie tickets, and were keen on participation. A few participants suggested that a "*combination of lottery with a coffee coupon for completing the task might work best*". However expensive incentives might nullify the positive effect of completing the DR message. Hence DR incentive system needs to be designed carefully. For future field trials, we chose to continue with the Lottery based incentive.

D. DR Message Feedback: Not Real-time vs Real-time

Data analysis revealed that real-time feedback of ongoing DR messages resulted in higher completion of the task, and higher energy savings. In terms of acceptance rate, we did not find much difference between the two design choices, with 44.4% acceptance rate for Not Real-time (7.8% declined and 47.8% not answered), and 51.1% for Real-time (6.7% declined and 42.2% not answered). This may be because while accepting/declining the message, the participant is unaware of the presence or absence of real-time feedback. With respect to acted rate, participants completed more DR task with real-time feedback (56.5%), compared to without feedback (37.5%). This can be attributed to the fact that participants were more aware of their current progress during an ongoing DR task, thus resulting in higher completion. During the interviews also, participants highly appreciated the real-time feedback, and "*enjoyed the battery design*" depicting the completion. Student's t-test showed that real-time feedback resulted in more energy conservation (on an average, 3.6 kWh per message, sd=3.9) compared to no real-time feedback (m=1.34, sd=0.9), with $t_{84}=5.1$, $p<0.05$.

VI. CONCLUSION

In this paper, we presented results from 6-month long residential DR field trials. The objective of the study was to study four aspects related to DR messages - notification mechanism, message type, associated incentive, and participation feedback. As per the results obtained from the trials, for DR message notification, we recommend using a combination of wall display for showing DR messages, and SMS for notifying the arrival of a new message. In addition, the DR message should provide specific tasks/actions to the user so as to minimize ambiguity. Moreover, during an ongoing DR message, real time information helps users to track their progress and aids them in achieving the DR targets. Lastly, savings from a DR program can be passed on to the consumers by the utility provider in the form of incentives. In particular, based on our findings, we recommend lottery-based incentives as an effective mechanism to motivate consumers to participate in DR programs.

The results of the field trial presented in this paper were limited because of the small number of participants. In future, we plan to conduct a larger field trial with more participants. Besides validating the current results on a larger scale, this would also enable us to understand the impact of demographic parameters, including education, occupation, income level and house size, on the acceptability of DR messages.

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