Multicast Communication for Demand Response in Smart Grid

Radha Rani Kandoori

Dept.of Electrical and Computer Engineering

Sungkyunkwan University

Suwon, South Korea

radhareddy@skku.edu

Navrati Saxena

Dept.of Electrical and Computer Engineering

Sungkyunkwan University

Suwon, South Korea navrati@skku.edu

Abstract

Smart Grid-The intelligent electricity grid empowers bi-directional communication between utility and its consumers. Unlike traditional grid, smart grid encourages consumers to participate in demand response program. Demand Response program allows the consumers to reduce or shift the energy usage from peak to off-peak period. This potentially offers energy efficiency. In this paper, we have proposed multicast communication for demand response messages using 3GPP LTE to reduce the power consumption. During peak energy consumption period, utility centers multicast a demand-response message to a group of residential users. The multicast message prompts the users to reduce their power usage to enforce energy efficiency. Because of limited resources, multicast is the most significant work to advertise messages to a group of smart grid users to reduce network traffic. Our model strives for green environment by reducing network traffic level and power consumption of users. We have simulated our proposed model in OMNET++ simulator using SimuLTE module. For power shortage of 20%, our protocol decreases round trip time up to 56.94% by using our multicast group with 40 users compared to 100 users.

Smart Grids; Demand Response; Residential Demand Response program; Energy Efficiency; Multicast; 4*G LTE networks; OMNET++.*

Introduction

Smart Grid (SG) is a new paradigm of the existing traditional electric grid. It is capable of monitoring all domains from generation plants to consumer's individual appliances [1]. SG provides Table 1: DR Communication Needs

Application	Bandwidth	Latency
Demand Response	14Kbps - 100Kbps per node/device	500ms - several minutes

the flexibility for users to participate in its operation. A primary key feature of SG is Smart meter (SM). SM enables bi-directional communication between utility and user. SM delivers the power consumption data of users to utility center. The utility center updates real-time electricity prices to end users through SM [2]. This information allows the users to react to price changes by reducing power usage, thereby participating in demand response programs. Demand Response (DR) is one of the key functionality of the SG that allows the consumers to reduce the energy consumption in the peak load hours or shift that usage to off-peak hours. When more users respond to DR program, power consumption is considerably reduced and we can aim for greener environment.

Electricity demand for a particular region fluctuate based on many factors like weather condition, temperature and time of the day etc. Even though load forecast prevails, prediction of peak demand is fluctuating due to the exogenous factors. Peak demand of electricity results in expensive electricity cost. The main reason for this is due to large operational expenditure (OPEX) of peak power plant. DR program can be a preferable solution to encounter blackouts and to reduce operational costs for utility centers. DR programs allows users to reduce their electricity usage during critical peak periods or to shift some of their peak demand operations to off-peak periods. It enables the dynamic adjustment of electricity demand in response to the price signals. The active participation of residential users to DR program curtails power usage levels, eventually becoming energy efficient. In particular, incentives improve the user participation in residential DR program. This paper proposes a multicast grouping protocol for residential users. Multicast has been envisaged to be used in DR programs since multicast messages delivered to a group of users by reducing network traffic.

Communication in DR programs plays an important role, as real-time action is needed to balance the power supply and demand [3]. 3GPP LTE is the most promising wireless technology, which can be used to support the SG communication due to its dynamic spectrum allocation from 1.4MHz to 20MHz [4]. It also provides support for a wide variety of bandwidth. For DR messages we mainly concentrate on the delay and support of the number of devices. This can be easily achieved by using LTE technology [5]. Table 1 shows the communication requirements for DR messages [6]. The Performance analysis of LTE based smartgrid Communications Network for uplink is analyzed in [7,8]. The study on feasibility of applying LTE to build low latency and high reliable smart grid network is given in [9]. DR program plays an active role to overcome the fluctuations in the power demand. Consumers electricity usage can be dynamically and intelligently adjusted to improve the grid network and make SG more reliable and efficient. Therefore, we must include the successful user participation in the DR messages. In our work we focus on DR at the residential user level for energy efficiency. The major contributions of our paper are:

1. We propose a protocol to balance the power demand and supply for DR.
2. Our protocol makes dynamic multicast groups to advertise the DR messages.
3. The protocol uses LTE network to send the multicast messages due to the latency requirements for DR messages.

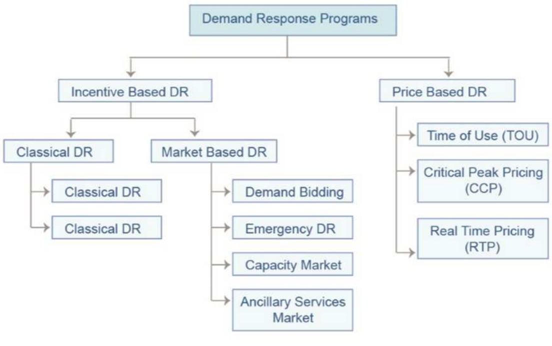

Figure 1: Classification of DR programs

4. In response to that DR messages, the responded users are rewarded with incentives to encourage their participation.
5. We analyze power usage for residential users.
6. We have done exhaustive simulation using OMNET++ simulator [10], INET framework [11] , and SimuLte modules [12].
7. We have simulated for 5%, 10%, 20% power shortage with 10, 20, 40 users respectively to meet the power requirement.
8. We have achieved the decrease in delay 67.43%, 62.6%, and 56.94% for 10, 20, 40 users respectively when compared to 100 users in group.

The rest of the paper is organized as follows. Section 2 discusses classification of DR programs. We elaborate our proposed multicast model for DR programs in Section 3. Section 4 illustrates the simulation setup and the results. Finally we conclude in section 5.

Related Work

Traditional grid is not capable of involving users in the electric network operations. Moving towards to SG users can play an important role in renewable energy production and usage. DR programs provides an opportunity for users to reduce the energy usage during peak periods. DR programs are classified into either Incentive based program (IBP) or Price based program (PBP) [13]. Figure 1 represents the classification of DR programs [14]. Curtailment programs come under IBP which can be used for residential users. The effect of residential DR on energy efficiency is studied in [15]. Residential DR programs effects the power reduction of peak load in an efficient manner [16,17].

To the best of our knowledge we have not found any grouping protocol for DR messages. The motivation behind our work for multicast group is to reduce the load in the network by not sending DR messages to all users. we have used LTE network for communicating our DR messages. If we send message to every user there will be a rebound effect. The power produced will be more than power consumed if all the users reduces the power. We will be wasting that power produced, because we can not store it.

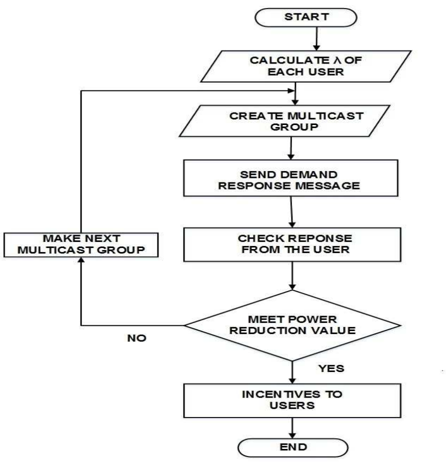

Figure 2: Flowchart representing our Protocol

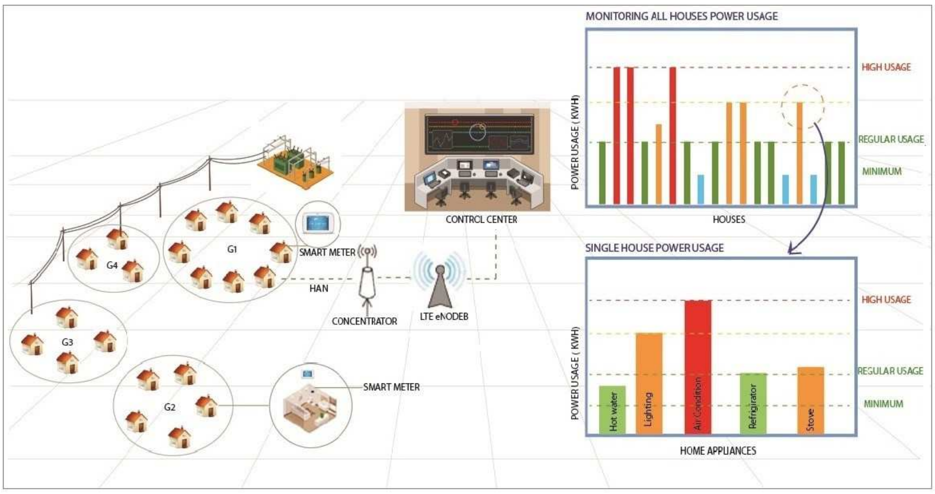

Figure 3: Multicast DR Communication In Residential Area Network

Our proposed protocol - DR Using Multicast communication

The objective of our work is to efficiently make the multicast group for sending DR messages. We aim to minimize the household's electricity usage by giving incentives(discounts) in their electricity bills. Our protocol sends the DR messages to the selected residential users to reduce the power consumption when the power demand increases for a particular time. Figure 3 shows our conceptual diagram of multicast communication for DR in LTE network. Figure 3 depicts the residential users using smart meters, the utility center and LTE network for communicating multicast messages. Utility center monitors the power usage of all the users. The red color bar in the diagram shows the high power usage users, orange color bar represents the threshold value power usage, green color bar depicts the regular usage power level for the users, and blue bar displays the minimum level power usage users. Our protocol makes various dynamic groups, by checking the power usage of those users to send the DR message. To achieve this the following tasks are performed.

1. The power usage of each user at that particular time of the DR program is calculated.
2. The user response participation index is calculated. It is calculated from the participation level of the previous DR program.

Power usage and user response factor α are the two key attributes of our protocol to make the dynamic multicast group for sending the DR message to residential users. If the power reduction is not met, the power requirement from the first multicast group then our protocol adjusts the second multicast group to send the DR message. Uniform distribution for power usage values of individual users and Zipf's distribution [18] with access skew coefficient θ for DR participation index is used. User rank index λ for each user is calculated. This can be represented mathematically as,

$$\lambda = \frac{P_i}{\sum_{i=1}^{N} P_i} + Zipf_i(\theta) \text{ ……………….. } \quad (1)$$

where P_i is the power used by user i, $\sum_{i=1}^{N} P_i$ is the total power used by users N, $Zipf_i(\theta)$ is the probability of user i participation in the DR program, and θ is the access skew-coefficient of Zipf's distribution.

The steps involved in our process is illustrated in Figure 2. After calculating λ from (1), users are sorted based on the descending order of their λ value to form the multicast group. Our protocol alerts the user group with DR messages for power reduction. users response for power reduction is monitored and checked for the required power reduction value. Our protocol dynamically increases or decreases the group size depending on the power reduction value. For achieving X% of power reduction 2times of power reduction% of users are selected from the total users. For 20% power reduction 40% users, and for 10%, 5% power reduction 20%, and 10% of users are selected. Based upon their response, the protocol decides to send message to other group or not. If the power reduction satisfies the power requirement then it is not sent to the other group otherwise the next batch of users are selected. It is dynamically related to how much power needs to be reduced and how many users are to be selected.

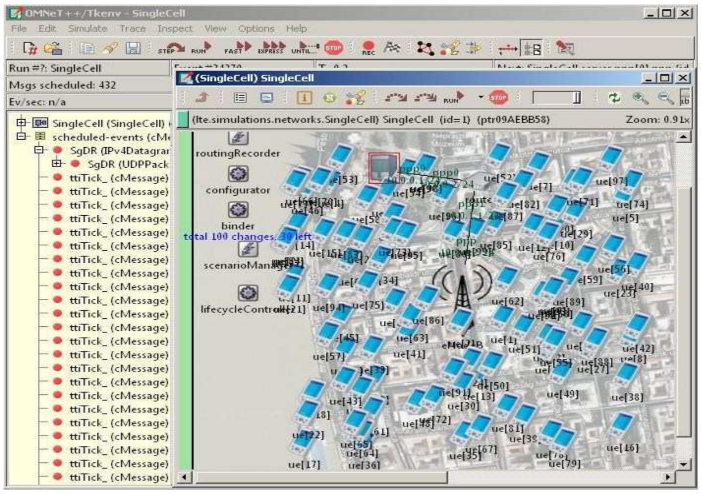

Figure 4: SGDR Application

Simulation Results

We have simulated our model using OMNET++ simulator. We have INET module for wireless networks and SimuLTE for LTE network model in OMNET++. Table 2 provides the principal SimuLTE simulation parameters employed for our DR program in a Smart Grid.

We have created our application named SgDR in SimuLTE to send the multicast messges for the power reduction to users. Figure 4 shows our SgDR application. The simulation model consists of one eNodeB and 100 users. The utility center uses LTE eNBs to communicate with the users using their smart meters. For power reduction utility center sends DR message in downlink to selected users in multicast group. In response to that user sends power reduction value in uplink.

In downlink we are sending our DR program multicast packet to a set of M multicast receivers from enodeB, where M is the multicast group size. We collected the power usage of 100 residential users and calculated the power usage for 15 minutes. Total average power for 100 users in 15 minutes is 9050 Watts. We considered 5%, 10%, 20% of this total power as power shortage. We have sent the the multicast message to 10, 20, 40 users for 5%, 10%, and 20% power reduction respectively. On receiving the multicast message from enodeB, users responds with the power reduction value of how much power they can reduce. Figure 5 represents the power reduction for these three cases. Four values of access skew-coefficient θ(0.2,0.4,0.6,0.8) in zipf's distribution is taken for our simulations. Power reduction values achieved by using our protocol are shown in Table 3 for all θ values. We met the required power for all these cases with our first multicast group only.

Table 2: Simulation Parameters

Parameter	Value
Carrier frequency	2 GHz
FDD channel bandwidth	2 × 1.4 MHz
Maximum UE Tx power	26 dBm
Maximum eNodeB Tx power	40 dBm
eNodeB height	25 m
UE height	1.5 m
No. of resource blocks DL 6	
No. of resource blocks UL 6	
cyclic prefix type	normal
No. of transmitters	1
No. of receivers	10, 20, 30, 40, 50

Table 3: Power Reduction

θ	5%**(**452.5**)W**	10%**(**905**)W**	20%**(**1810**) W**
0.2	463.5W	894.3W	1774 W
0.4	443.3W	1027.2W	1962 W
0.6	489.5W	956.6W	2011 W
0.8	480.8W	930.8W	1839 W

Figure 6 depicts the dynamic multicast group and individual round trip time (RTT) of each user in the group. Multicast group size of 10, 20, 30, 40 users are shown respectively. We infer from the Figure 6, the highest RTT in 10 users is 39 ms. The group size with 20, 30, 40 users the highest RTT is 41 ms, 54 ms, and 61 ms respectively. It is showing the increasing trend with the number of users.

Figure 7 illustrates the average round trip time (RTT) for the different users in the groups. As seen in Figure 7, 10 users have the lowest average RTT with value of 23.3 ms. The average RTT for 20 users is 26.49 ms, 30 users have slightly higher values as compared to 20 users with an average RTT of 28.77 ms. The average RTT values for 40, 50 users is 30.4 ms, 35.59 ms respectively. For 100 users the average RTT is 70.6 ms. Therefore, we achieved the decrease in average RTT values by sending message to our multicast group instead of sending message to 100 users.

Conclusion

In this paper we have proposed an efficient multicast DR program over LTE network for residential users. Dynamic multicast group effectively reduces the power consumption for DR messages. We focused on LTE multicast communication for signaling users in Demand response message. Our simulation results in OMNET++, SimuLTE module shows the effective decrease in power consumption to meet the power requirement. Simulation results also indicates the decrease in average RTT values for our multicast group compared to 100 users. The acknowledgement from only selected users in SG communication reduces the traffic congestion in the LTE network.

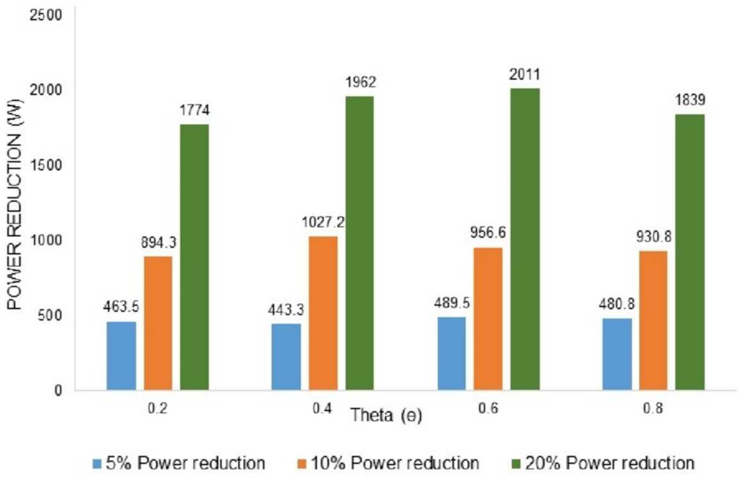

Figure 5: Power Reduction for different scenarios

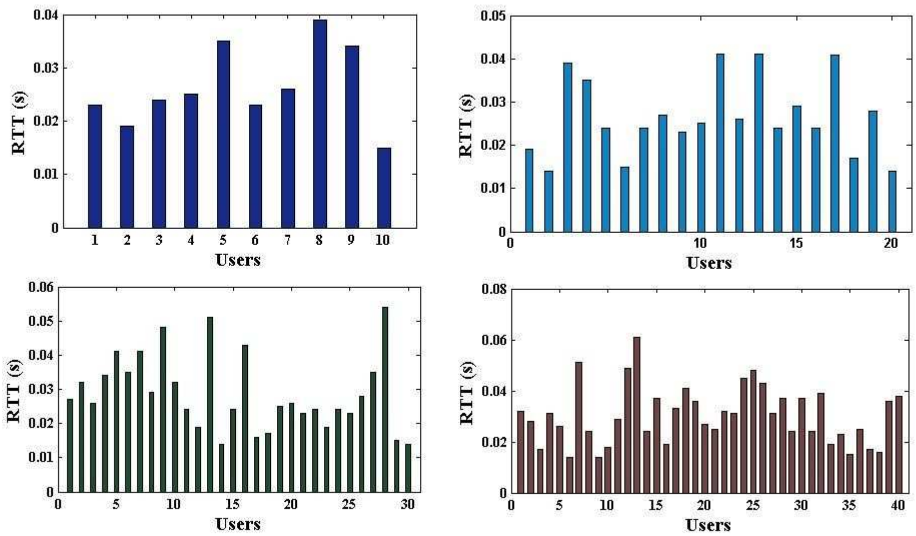

Figure 6: Dynamic multicast group

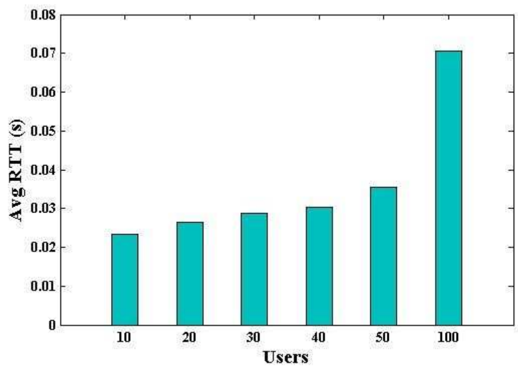

Figure 7: Average RTT for different users

References

[1] B. Hamilton and M. Summy, “Benefits of the smart grid”, *IEEE Power Energy Magazine*, vol. 9, no. 1, pp. 104–102, Jan.–Feb. 2011.

[2] James Momoh, “Smart Grid: Fundamentals of Design and Analysis.”

[3] YuzheXu, Carlo Fischione, “REAL-TIME SCHEDULING IN LTE FOR SMART GRIDS,” *Proceedings of the 5th International Symposium on Communications, Control and Signal Processing, ISCCSP* , Rome, Italy, 2-4 May 2012.

[4] TAN Chong1, YU Kai1, CHEN Shi2, SU Han3, WANG Haifeng2, BU Zhiyong1, “Distributed Channel Allocation Scheme based on LTE System in Smart Grid”

[5] Muhammad Basit Shahab, Asif Hussain, and Muhammad Shoaib, “Smart Grid Traffic Modeling and Scheduling Using 3GPP LTE for Efficient Communication with Reduced RAN Delays” TSP 2013: 263-267

[6] ”Communication Requirements of Smart Grid Technologies,” US Department of Energy, Oct. 5, 2010, [online] Available: http://www.greendmv.org

[7] Jason Brown, Jamil Y. Khan, ”Performance comparison of LTE FDD and TDD based Smart Grid communications networks for uplink biased traffic.” *SmartGridComm* , 276-281, 2012

[8] Jason Brown, Jamil Y. Khan: ”Performance analysis of an LTE TDD based smart grid communications network for uplink biased traffic.” *GLOBECOM Workshops* ,1502-1507, 2012

[9] Peng Cheng, Li Wang, Bin Zhen, and Shihua Wang ”Feasibility Study of Applying LTE to Smart Grid”, *IEEE First International Workshop on Smart Grid Modeling and Simulation (SGMS)* , 2011

[10] ”OMNET++ Network Simulation Framework”, [online] Available: www.omnetpp.org

[11] ”INET Framework”, [online] Available: www.inet.omnetpp.org

[12] ”SimuLTESystem level Simulator” [online] Available: www.simulte.com

[13] K.P. Schneider, J.C. Fuller, and D. Chassin, ”Analysis of distribution level residential demand response,” *Power Systems Conference and Exposition (PSCE), IEEE/PES*, vol., no., pp.1-6, 20-23 March 2011.

[14] A. Cuevas, C. Lastres, Caffarel, R. Mart nez, and A. Santamara, Next generation of Energy Residential Gateways for Demand Response and Dynamic Pricing,” *Consumer Electronics (ICCE), IEEE International Conference*, vol., no., pp.543-544, 9-12 Jan. 2011.

[15] Ward Jewell, “The Effects of Residential Energy Efficiency on Electric Demand Response Programs,” *IEEE Computer Society, 2014 47th Hawaii International Conference on System Science*.

[16] Ying Li and Mark Trayer, ”Automated residential demand response: Algorithmic implications of pricing models,” *Consumer Electronics (ICCE), IEEE International Conference*, vol., no., pp.626-629, 13-16 Jan. 2012.

[17] S. Tiptipakorn, and Wei-Jen Lee, ”A Residential Consumer-Centered Load Control Strategy in Real-Time Electricity Pricing Environment,” *Power Symposium, 2007. NAPS ’07. 39th North American*, vol., no., pp.505-510, Sept. 30 2007-Oct. 2 2007.

[18] R. Gunther, L. Levitin, B. Shapiro, P. Wagner (1996), ”Zipf’s law and the effect of ranking on probability distributions”, *International Journal of Theoretical Physics*, 35(2):395-417