Energy-Efficient Smart Metering for Green Smart Grid Communication

Samaresh Bera, Sudip Misra
School of Information Technology
Indian Institute of Technology
Kharagpur, 721302, India
Email: {samaresh, smisra}@sit.iitkgp.ernet.in

Mohammad S. Obaidat
Fellow of IEEE, *Fellow of SCS*
Department of Computer Science and Software Engineering
Monmouth University, West Long Branch, NJ, USA
Email: obaidat@monmouth.edu

***Abstract*—In a smart grid, smart meters are expected to be the key technology to support bi-directional information exchange between service providers and end-users. The on-growing demand of smart meters (residential customers and plug-in hybrid electric vehicles) would result in huge energy consumption, while communicating with the entities in the smart grid. Therefore, green wireless communication technologies are expected to help in reducing their impact on environment. Therefore, it is important to design energy-efficient schemes that can reduce CO_2 emissions and cost-effective energy management in the smart grid. In this paper, an energy-efficient smart metering scheme is proposed — an effort towards minimizing the energy consumption by the smart meters for green smart grid communication. We incorporate the use of *coalition* game to form multiple coalitions among smart meters to communicate with the service provider. We show that there exists a stable condition of the coalitions for which the payoff values of the smart meters are maximized. The simulation results show that using the proposed approach, energy consumption by the smart meters can be reduced, which, in turn, would enable green wireless communication in the smart grid.**

***Index Terms*—Green Communication, Coalition Game, Energy Efficient, Smart Meter, PHEVs, Smart Grid.**

I. INTRODUCTION

Ongoing concerns about climate change and environment protection, while meeting the increasing demand for wireless communication, is one of the biggest threats [1]. A smart grid is conceptualized as a combination of underlay electrical network and overlay communication network. Therefore, the communication network plays an important role for exchanging real-time information. Consequently, the smart meters deployed at the customers' end communicate with the service provider for cost-effective and reliable energy supply to the users. Therefore, the exponential growth in the number of the smart meters increases the green house gas emissions [2]. Therefore, it is necessary to establish a green wireless communication architecture that takes into account the environmental issues [3], [4].

The smart meters are expected to communicate with the service providers within a time interval (for example, every 10 minutes) [5]. Therefore, the smart meters consume huge amount of energy for real-time communication. On the other hand, plug-in hybrid vehicles (PHEVs) play an important role to relieve the on-peak hour load from the grid, and acts as storage device as well [6]. Intuitively, PHEVs will also communicate with the service provider in order to have real-time information. Therefore, implementation of cooperative strategies of smart meters and PHEVs can have significant impact in reducing the energy consumption in smart grids. Consequently, it is important to propose an energy-efficient technique for smart metering towards green wireless communications in the smart grid.

In this paper, we propose an energy-efficient smart metering technique in the smart grid, an effort towards the development of green wireless communication. In such a scenario, the *coalition* game framework is used to form coalitions among smart meters and PHEVs. Consequently, the smart meters and PHEVs maximize their payoff by forming coalitions among themselves. We also show that a stable condition is achieved, while forming coalitions among the smart meters and PHEVs. The algorithm for joining a coalition and splitting from it is also presented.

The rest of the paper is organized as follows. Section II presents a brief overview of the existing literature in the context of minimizing energy consumption in the smart grid. Architecture of the proposed scheme is presented in Section III. The coalition formation game is presented in Section IV. Section V discusses the performance of the proposed scheme. Finally, Section VI concludes the paper while giving some future research directions.

II. RELATED WORKS

In the recent past, several research works are done in the context of energy-efficient smart grid communication and energy management [7]–[17]. Yan et al. [7] proposed a secure data aggregation scheme in the smart grid with the implementation of home area networks (HAN). In such a scenario, the real-time information is dispatched to the service provider, while keeping the customers' information confidential. Additionally, the authors also introduced an orthogonal chip code for coupling the smart devices tightly in the neighborhood area. In [8], the authors studied an energy-efficient scheme for heterogeneous networks, cognitive radios, and smart grid are incorporated jointly. In such a scenario, interference pricing policy is proposed in order to avoid the interference caused by different entities in the network. Bu et al. [9] used Stackelberg game to study the dynamics of the smart grid supported by green wireless communication. The authors showed that smart grid has significant impact on green wireless communication, and CO_2 emissions can also be reduced.

Sun et al. [10] analyzed the impact of different relaying strategies used in the conventional wireless networks in the context of smart grid applications. The authors showed that with the implementation of relay nodes at the customers' area, energy-efficient smart metering and demand response can be achieved. However, there are several issues while deploying relay nodes at the customers' end (such as optimal deployment and energy constraint). On the other hand, a cooperative transmission of meter data is proposed by Niyato et al. [12]. In their work, data aggregator units (DAUs) and meter data management systems (MDMS) are incorporated to collect the smart meter data in real-time. The smart meters communicate with the DAUs, which, in turn, communicate with the MDMS to exchange the real-time information. In [14], reliability of smart grid data communication is studied, while incorporating the DAUs and MDMS. The authors considered a load scheduling approach in which the customers' demands can be deferred in other time periods. The constrained Markov decision process is used to analyze the proposed scenario in the context of data communication reliability.

Misra et al. [13] discussed the importance of learning automata (LA) to maximize the utility for energy management in a smart grid. The authors showed that the dynamics of energy consumption and decision making by customers can be studied effectively using the proposed scheme. Energy harvesting smart metering approach is proposed in order to increase the data communication reliability while increasing the privacy as well [15]. In such a scenario, the smart meters harvest energy from environment. The authors showed that using the energy harvesting smart metering technique, both efficiency and privacy of the users can be increased.

The analysis of the existing technologies reveals that very few research works (eg. [8]–[10]) discuss the issue of energy-efficient smart metering for reliable smart grid communication. Therefore, in this paper, we propose an energy efficient smart metering approach towards green smart grid communication.

III. SYSTEM MODEL

Let there be N smart meters deployed at the customers' end, where $\mathcal{N}$ is the set of smart meters and PHEVs, which is denoted as $\mathcal{N} = \{1, 2, ..., N\}$. All the smart meters have variable communication range. The smart meters act as ordinary devices and relays as well. Figure 1 shows the deployment architecture. In such a scenario, smart meters form multiple coalitions for which the energy consumption cost is minimized, while communicating with the utility provider. The smart meter, which acts as a relay sends the real-time information of other smart meters to the base station. Eventually, the information is sent to the service provider from the base station. Plug-in electric vehicles (PHEVs) also take part in the communication process to the base station. Therefore, the structure of the coalition also depends on the availability of the PHEVs, as shown in Figure 1.

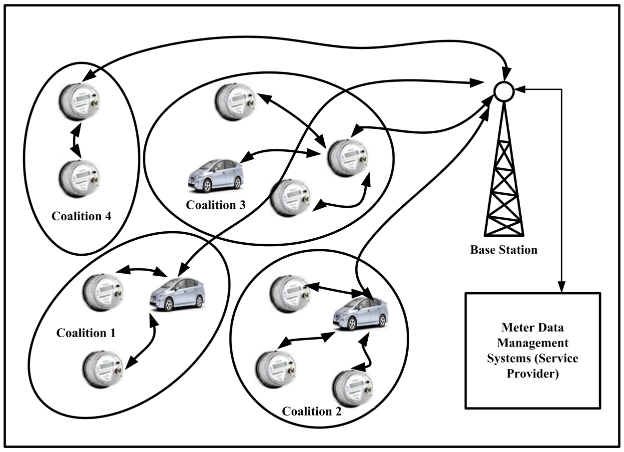

Fig. 1: Coalition formation among the smart meters

A. Energy Consumption Model

The smart meters communicate with the base station for exchanging real-time information with the service provider, as discussed earlier. The energy consumed by a smart meter or a PHEV i for communicating with the base station in different time-slots is denoted in vector form as follows:

$$x_i = [x_i^1, x_i^2, ..., x_i^t, ..., x_i^T] \tag{1}$$

where T is the total time period in a day. On the other hand, the objective of the smart meters is to minimize the energy consumption cost in order to maximize their utilities, while maintaining reliable data delivery. Therefore, the objective function of the smart meter and the PHEV is presented as follows.

$$\text{Minimize} \sum_{t=1}^{T} x_t.p_t$$

subject to

$$p_t^{min} \leq p_t \leq p_t^{max} \tag{2}$$

$$\delta_t \leq \Delta_{max} \tag{3}$$

where p_t is the cost incurred by the smart meters and the PHEVs for unit energy consumption. Equation (2) denotes that the real-time cost p_t has a minimum and a maximum value. On the other hand, delay δ for the data delivery must be less than or equal to the maximum allowable delay Δ_{max} for reliable data delivery.

IV. COALITION GAME FORMULATION

As discussed in Section III, there are N smart meters, which are considered as the players of the game. Therefore, 2^N is the set of all possible coalitions among the N players. The coalition with all the players is called a *grand* coalition [18]. We assign a characteristic function in any coalition $\mathcal{S} \subseteq 2^N$ as a real number $\mathcal{C}(\mathcal{S})$. Thus, $\mathcal{C}(\mathcal{S})$ is the maximum common payoff that the players in the coalition $\mathcal{S}$ can obtain, while cooperating with each other within the coalition. Therefore, the players form coalitions among themselves, depending on the payoff values obtained from the coalition to reduce the energy consumption.

The distribution of the payoff among the players in a coalition $\mathcal{S}$ can be expressed in the vector form as $\mathcal{P} = \{p_1, p_2, ..., p_N\}$ with N players. According to the coalition game [18]–[20], the total pay-off is equally distributed among all the players in the coalition. Therefore, the following condition holds for all the coalitions:

$$\sum_{i=1}^{N} p_i = \mathcal{C}(\mathcal{N}) \tag{4}$$

where $\mathcal{C}(\emptyset) = 0$, i.e., the core of the coalition is empty.

Let there be $\mathcal{W}$ partitions and let s be the total number of coalitions in the partition. Therefore, $\mathcal{W}$ is as follows:

$$\mathcal{W} = \{\mathcal{S}_1, \mathcal{S}_2, ..., \mathcal{S}_s\} \tag{5}$$

where all the coalitions are disjoint, i.e., $\mathcal{S}_i \cap \mathcal{S}_j = \emptyset$ and $i \neq j$, $\sum_{i=1}^{s} = \mathcal{N}$. Therefore, the total number of possible different partitions $(\mathcal{D})$ for N players is obtained using the Bell function as follows [19].

$$\mathcal{D}_N = \sum_{i=1}^{N} \binom{N-1}{i} \mathcal{D}_i, \qquad \text{for } i \geq 1 \text{ and } \mathcal{D}_0 = 1 \tag{6}$$

Assumption 1. *We consider the coalition game as a non-transferable utility (NTU) game, i.e., the sum of payoffs defined in Equation (4) cannot be transferred randomly among the players in the coalition.*

Definition 1. *A coalition game $\mathcal{G}$ is super-additive if and only if every pair of different coalitions is disjoint, i.e.,*

$$\mathcal{G}(\mathcal{S}_i \cup \mathcal{S}_j) \geq \mathcal{G}(\mathcal{S}) \tag{7}$$

where $\mathcal{S}_i \cap \mathcal{S}_j = \emptyset$ and $i \neq j$.

The solution of the proposed coalition game $\mathcal{G}$ depends on the coalition structure $\mathcal{W}$. The stability of the structure is defined as follows.

- Within a coalition, none of the players can maximize his/her individual payoff by leaving the coalition or by acting as a player without joining in any coalition. Mathematically,

$$p_i(\mathcal{S}) \geq \mathcal{C}(i) = p_i(i) \tag{8}$$

- A coalition $\mathcal{S}_i \in \mathcal{W}$ is stable if no other coalition $\mathcal{S}_j \in \mathcal{W}$ can improve its total payoff by joining with the coalition $\mathcal{S}_i$. Mathematically,

$$\mathcal{C}(\mathcal{S}_j) \geq \mathcal{C}(\mathcal{S}_i \cup \mathcal{S}_j) - \mathcal{C}(\mathcal{S}_i) \tag{9}$$

where $\mathcal{S}_i \cap \mathcal{S}_j = \emptyset$ and $\mathcal{S}_i, \mathcal{S}_j \in \mathcal{W}$.

A. Joining a Coalition

More than one (multiple) coalitions $\mathcal{S}_j$, $j \in \mathcal{M}^*$, where $\mathcal{M}^*$ is a set of different coalitions and $\mathcal{S}_j^{(\{i\})}$ is the i^{th} coalition in the set $\mathcal{M}^*$, form a joint coalition $\mathcal{S}_{j'}^{(\{i*\})}$ if and only if the new payoff value $\big(\mathcal{P}_i(\mathcal{S}_{j'}^{(\{i*\})})\big)$ for the new coalition is greater than the payoff value $\big(\mathcal{P}_i(\mathcal{S}_j^{(\{i\})})\big)$ with the existing coalition. Mathematically,

$$\Big(\mathcal{P}_i\big(\mathcal{S}_{j'}^{(\{i*\})}\big)\Big) > \Big(\mathcal{P}_i\big(\mathcal{S}_j^{(\{i\})}\big)\Big) \tag{10}$$

and

$$\Big(\mathcal{P}_{i'}\big(\mathcal{S}_{j'}^{(\{i*\})}\big)\Big) > \Big(\mathcal{P}_{i'}\big(\mathcal{S}_{j'}^{(\{i*\})}\big) - \mathcal{S}_j^{(\{i\})}\Big) \tag{11}$$

for $i \in \mathcal{S}_j^{(\{i\})}$ and $i^{'} \in \Big(\mathcal{S}_{j'}^{(\{i*\})} - \mathcal{S}_j^{(\{i\})}\Big)$, where $\mathcal{S}_{j'}^{(\{i*\})} = \sum_{j \in \mathcal{M}^*} \mathcal{S}_j^{(\{i\})}$. Therefore, a group of players within a coalition forms a new coalition, when the players' payoff values are maximized by forming multiple coalitions rather than a single coalition.

B. Splitting a Coalition

Similar to joining a coalition, a coalition can be partitioned into different coalitions. A coalition $\mathcal{S}_j$ can be splitted into multiple coalition with a group of players if and only if the payoff value of the players in the coalition increases after partitioning the coalition. Mathematically,

$$\Big(\mathcal{P}_i\big(\mathcal{S}_{j'}^{(\{i*\})}\big)\Big) > \Big(\mathcal{P}_i\big(\mathcal{S}_j^{(\{i\})}\big)\Big), \qquad \forall i \in \mathcal{S}_j^{(\{i\})} \tag{12}$$

C. Equilibrium Strategy of the Players

To find the stable state of a coalition $\mathcal{S}$, a finite Markov chain is formulated [19] with the state space as follows.

$$\Omega = \Big\{\omega = \big(\mathcal{W}, d\big) | \mathcal{W} \in W, d \in \times_{i \in N} \mathcal{D}_i\Big\} \tag{13}$$

where W is the set of coalition structures, and $\mathcal{W}$ is a coalition structure. Demand of a player i in state ω is calculated as follows:

$$d_i(\omega) = \max_{\mathcal{S} \in \mathcal{W} \cup \{\emptyset\}} \mathcal{P}\big(\mathcal{S} \cup \{i\}\big) - \sum_{j \neq i, j \in \mathcal{S}} d_j, \text{such that } d_i \in \mathcal{D}_i \tag{14}$$

and the coalition $\mathcal{S}_i(\mathcal{W})$ is calculated as follows:

$$\mathcal{S}_i(\mathcal{W}) \in \Big(\arg\max_{\mathcal{S} \in \mathcal{W} \cup \{\emptyset\}} \mathcal{P}\big(\mathcal{S} \cup \{i\}\big) - \sum_{j \neq i, j \in \mathcal{S}} d_j\Big) \tag{15}$$

Let $\mathcal{S}(i)$ be the coalition with player i, which belongs to any state ω. Therefore, the transition probability to reach from state ω to $\omega^{'}$ is as follows [19].

$$\phi_{\omega \to \omega'} = \Big\{\Pi_{i \in \mathcal{M}_{\omega \to \omega'}} \gamma \beta_i\big(\omega^{'} | \omega\big)\big(1 - \gamma\big)^{N - \mathcal{M}_{\omega \to \omega'}}\Big\} \tag{16}$$

where β_i is the best-reply rule of player i, i.e., $\beta_i\big(\omega^{'} | \omega > 0\big)$ if and only if Equation (14) holds. γ is the probability of getting a chance to move with given state ω. $\mathcal{M}_{\omega \to \omega'}$ is the set of players who have switched in a coalition in order to reach the state $\omega^{'}$ from the state ω, and strategy of the i^{th} player is $\big(d_i^{'}, \mathcal{S}^{'}(i)\big)$.

Theorem 1. *The proposed coalition game has at least one absorbing state for the condition i.e.,* $\sum_{i \in \mathcal{S}} \mathcal{P}(\{i\}) \leq \mathcal{P}(\mathcal{S})$ *[19].*

Proof. The property $\sum_{i \in \mathcal{S}} \mathcal{P}(\{i\}) \leq \mathcal{P}(\mathcal{S})$ implies $\mathcal{P}(\mathcal{N}) \geq \sum_{i \in \mathcal{N}} \mathcal{P}(\{i\})$. Assume the grand coalition formed with N players, where the individual payoff of each player is $p_i \geq \mathcal{P}(\{i\})$ with $\sum_{i \in \mathcal{N}} p_i = \mathcal{P}(N)$. Therefore, no player has incentive of forming single coalition. On the other hand, after forming the grand coalition, there is no other coalition to join. Consequently, no player can increase his/her demand $(d_i, i \in N)$ after forming the grand coalition. Thus, each element of the set:

$$\Omega^N(\mathcal{P}) := \Big\{ \omega = (\mathcal{W}, d) | \mathcal{W} = \{N\}, d_i \geq \mathcal{P}(\{i\}) \Big\}$$

$$\forall i \in N, \sum_{i=1}^{N} d_i = \mathcal{P}(N) \quad (17)$$

is an absorbing state under the condition $\sum_{i \in \mathcal{S}} \mathcal{P}(\{i\}) \leq \mathcal{P}(\mathcal{S})$. □

After forming the stable coalition, the payoff obtained by any individual player i is represented as follows.

$$\mathcal{U}_i = \sum_{k=1}^{\mathcal{D}_N} \pi_{\omega_k} p_i(\mathcal{S}_j^i), \qquad \text{for } \mathcal{S}_j^i \in \omega_k \quad (18)$$

where ω_k is the probability that the partition $\mathcal{W}$ will be formed. Therefore, the total utility of all the players is obtained as:

$$\mathcal{U}_t = \sum_{k=1}^{\mathcal{D}_n} \pi_{\omega_k} \sum_{\mathcal{S}_j \in \omega_k} \mathcal{P}(\mathcal{S}_j) \quad (19)$$

D. Algorithm

According to the payoff values for joining in a coalition or splitting it is defined in Sections IV-A and IV-B, respectively. All the players form coalitions, for which their payoff values are maximized. The algorithm for the smart meters in the decision making process is presented in Algorithm 1.

V. RESULTS AND DISCUSSION

A. Simulation Settings

To simulate the overall scenario, we use NS-3 (http://www.nsnum.org). Table I shows all the parameters used in the simulation. We evaluate the results for the proposed approach, while comparing with the traditional one (without forming any coalition). Consequently, the results are evaluated for the parameters as follows — energy consumption, delay, and network lifetime.

1) Energy Consumption: Figure 2 shows the total energy consumed by each customer for communicating with the service provider. The energy consumption by the customers is evaluated with the proposed approach and with the traditional one (i.e., without forming coalitions) as well. We see that customers' energy consumption is very low to communicate with the service provider, while cooperating to form the coalitions among themselves. On the other hand, energy consumption by the customers is quite high, while they behave selfishly, i.e., the customers are non-cooperative. Intuitively, the emissions of CO_2 can be reduced significantly.

Algorithm 1: Algorithm for Coalition Formation

```
Input: Number of players, $N$, Coalitions at time $t = 0$:
       $\{\mathcal{S}_1(t), \mathcal{S}_2(t), ..., \mathcal{S}_s(t)\}$
Output: Stable coalitions at time $(t+1)$ with the $N$
        players for all coalitions
Calculate individual payoff $\mathcal{P}(i)$ without joining in any
coalition or payoff $\mathcal{P}(\mathcal{S}_j)$ with the current coalition;
Merge Multiple Coalition;
if $\Big(\mathcal{P}_i\big(\mathcal{S}_{j'}^{(\{i*\})}\big)\Big) > \Big(\mathcal{P}_i\big(\mathcal{S}_j^{(\{i\})}\big)\Big)$ then
    Merge coalitions $\mathcal{S}_j(t)$ for $j \in \mathcal{M}^*$;
else
    if $r \leq \alpha$ then
        Merge coalitions $\mathcal{S}_j(t)$ for $j \in \mathcal{M}^*$;
Split a Coalition;
if $\Big(\mathcal{P}_i\big(\mathcal{S}_{j'}^{(\{i*\})}\big)\Big) > \Big(\mathcal{P}_i\big(\mathcal{S}_j^{(\{i\})}\big)\Big), \quad \forall i \in \mathcal{S}_j^{(\{i\})}$ then
    Split coalition $\mathcal{S}_j^{(\{i\})}(t)$ into $\mathcal{S}_{j'}^{(\{i*\})}$ for $j' \in \mathcal{M}'$;
else
    if $r \leq \alpha$ then
        Split coalition $\mathcal{S}_j^{(\{i\})}(t)$ into $\mathcal{S}_{j'}^{(\{i*\})}$ for $j' \in \mathcal{M}'$;
$t = (t+1)$;
```

TABLE I: Simulation Parameters

Parameter	**Value**
Simulation area	500 m ×500 m
Number of Base-stations	1
Number of Customers (smart meters and PHEVs)	50
Simulation time	720 sec
Battery energy	300 unit

The total energy consumption in the network is also evaluated. Figure 3 shows the total energy consumption in the network. We see that the energy consumption in the network is significantly reduced with the proposed scheme than that with the traditional one. Intuitively, the cost incurred by the customers for communicating with the service provider is also less than the traditional one. Therefore, the proposed scheme gives better performance for establishing a cost-effective smart grid environment.

2) Delay: The delay incurred by the customers is presented in Figure 4. Due to the decision making process in coalition formation, we see that delay incurred by the customers with the proposed scheme is higher than the traditional one. However, the delay with the proposed approach is quite considerable, while saving a huge amount of energy, as shown

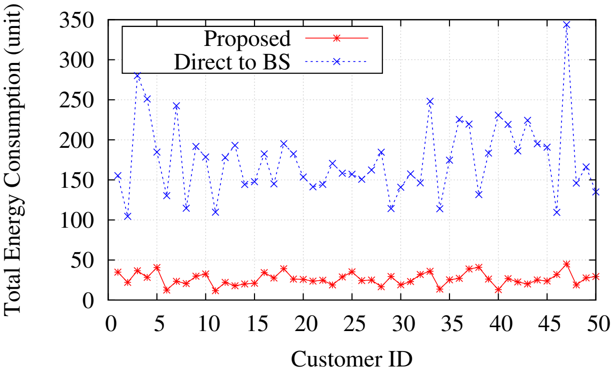

Fig. 2: Energy consumed by each customer for communication

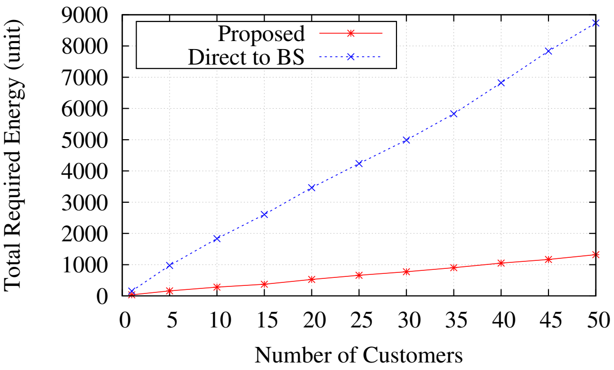

Fig. 3: Total energy consumption in the network

in Figures 2 and 3.

Similar to Figure 3, total delay in the network is also shown in Figure 5. Here, we also see that the delay occurred in the network with the proposed scheme is higher than the traditional one. However, the overall delay with the proposed approach is considerable.

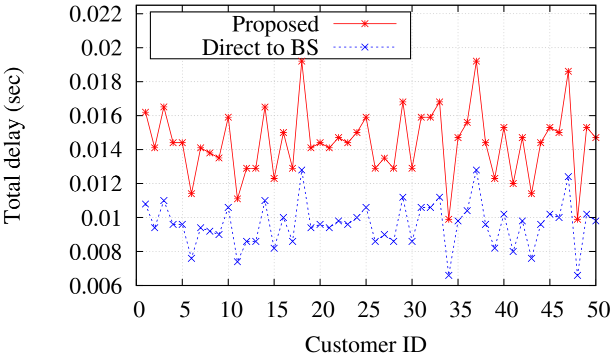

Fig. 4: Delay incurred by individual customer

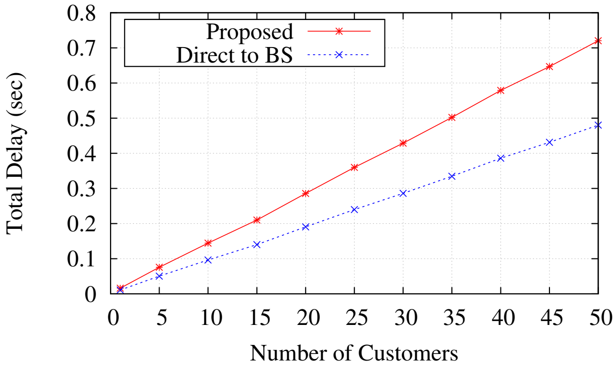

Fig. 5: Total delay incurred by customers in the network

3) Network Lifetime: We evaluate the network lifetime of a smart grid with the parameters presented in Table I. Figure 6 shows the lifetime of the network (with the proposed scheme) is significantly higher than the traditional one (without forming coalition). Therefore, for a battery constrained smart grid network, the proposed scheme outperforms the traditional one for a long run.

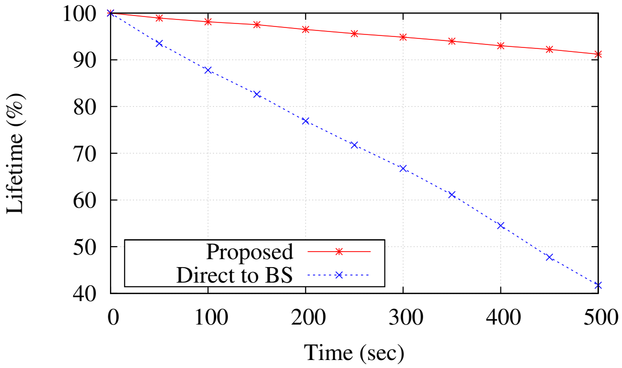

Fig. 6: Lifetime of the network

VI. CONCLUSION

In this paper, we proposed an energy-efficient smart metering technique for green wireless smart grid communication. *Coalition* game framework is used to form coalitions among smart meters and PHEVs. The smart meters and the PHEVs form coalitions for which their payoff values are maximized. The simulation results show that the proposed scheme has significant impact to reduce the energy consumption by the smart meters and PHEVs up to a certain extent, which, in turn, leads to green communication in the smart grid.

The future extension of this work includes the improvement of the proposed scheme to reduce energy consumption further by the smart meters and PHEVs. Currently, in this work, we do not incorporate the security issues, while forming coalition among the players. We assumed that all the players cooperate to form coalitions. Therefore, we also need to take into account the non-cooperative strategy of the players as a future extension of this work.

REFERENCES

[1] A. Fehske, G. Fettweis, J. Malmodin, and G. Biczok, “The Global Footprint of Mobile Communications: The Ecological and Economic

Perspective,” *IEEE Communications Magazine*, vol. 49, no. 8, pp. 55 – 62, Aug. 2011.
[2] F. Saghezchi, A. Radwan, J. Rodriguez, and T. Dagiuklas, “Coalition formation game toward green mobile terminals in heterogeneous wireless networks,” *IEEE Wireless Communications*, vol. 20, no. 5, pp. 85 – 91, Oct. 2013.
[3] D. Feng, C. Jiang, G. Lim, L. J. C. Jr., G. Feng, and G. Y. Li, “A Survey of Energy-Efficient Wireless Communications,” *IEEE Communications Surveys and Tutorials*, vol. 15, no. 1, pp. 167 – 178, 2013.
[4] S. Bera, S. Misra, and J. J. P. C. Rodrigues, “Cloud Computing Applications for Smart Grid: A Survey,” *IEEE Transactions on Parallel and Distributed Systems*, 2014, DOI: 10.1109/TPDS.2014.2321378.
[5] H. Li, Z. Han, L. Lai, and R. C. Qiu, “Efficient and reliable multiple access for advanced metering in future smart grid,” in *Proc. of IEEE SmartGridComm*, Brussels, Oct. 2011, pp. 440 – 444.
[6] S. Misra, S. Bera, and T. Ojha, “D2P: Distributed Dynamic Pricing Policy in Smart Grid for PHEVs Management,” *IEEE Transactions on Parallel and Distributed Systems*, 2014, DOI: 10.1109/TPDS.2014.2315195.
[7] Y. Yan, Y. Qian, and H. Sharif, “A Secure Data Aggregation and Dispatch Scheme for Home Area Networks in Smart Grid,” in *Proc. IEEE GLOBECOM*, Houston, TX, Dec. 2011, pp. 1 – 6.
[8] S. Bu and F. R. Yu, “Dynamic energy-efficient resource allocation in cognitive heterogeneous wireless networks with the smart grid,” in *Proc. of IEEE GLOBECOM*, Anaheim, CA, Dec. 2012, pp. 3032 – 3036.
[9] S. Bu, F. R. Yu, Y. Cai, and P. X. Liu, “Dynamic operation of BSs in green wireless cellular networks powered by the smart grid,” in *Proc. IEEE GLOBECOM*, Anaheim, CA, Dec. 2012, pp. 5201 – 5205.
[10] H. Sun, A. Nallanathan, B. Tan, and J. S. Thompson, “Relaying Technologies for Smart Grid Communications,” *IEEE Wireless Communications*, vol. 19, no. 6, pp. 52 – 59, Dec. 2012.
[11] D. Niyato, X. Lu, and P. Wang, “Adaptive power management for wireless base stations in a smart grid environment,” *IEEE Wireless Communications*, vol. 19, no. 6, pp. 44 – 51, Dec. 2012.
[12] D. Niyato and P. Wang, “Cooperative transmission for meter data collection in smart grid,” *IEEE Communications Magazine*, vol. 50, no. 4, pp. 90 – 97, April 2012.
[13] S. Misra, P. V. Krishna, V. Saritha, and M. S. Obaidat, “Learning automata as a utility for power management in smart grids,” *IEEE Communications Magazine*, vol. 51, no. 1, pp. 98–104, 2013.
[14] D. Niyato, Q. Dong, P. Wang, and E. Hossain, “Optimizations of Power Consumption and Supply in the Smart Grid: Analysis of the Impact of Data Communication Reliability,” *IEEE Transactions on Smart Grid*, vol. 4, no. 1, pp. 21 – 35, March 2013.
[15] O. Tan, D. Gunduz, and H. V. Poor, “Increasing Smart Meter Privacy Through Energy Harvesting and Storage Devices,” *IEEE Journal on Selected Areas in Communications*, vol. 31, no. 7, pp. 1331 – 1341, July 2013.
[16] S. Misra, A. Mondal, S. Banik, M. Khatua, S. Bera, and M. S. Obaidat, “Residential Energy Management in Smart Grid: A Markov Decision Process-Based Approach,” in *Proc. of IEEE iThings/CPSCom*, Beijing, Aug. 2013, pp. 1152 – 1157.
[17] S. Misra, S. Bera, and M. S. Obaidat, “Economics of Customer’s Decisions in Smart Grid,” *IET Networks*, vol. 3, no. 2, p. 7, 2014.
[18] P. Shenoy and Lawrence, “On Coalition Formation: A Game-Theoretical Approach,” *Intl. Journal of Game Theory*, vol. 8, no. 3, pp. 133 – 164, 1979.
[19] T. Arnold and U. Schwalbe, “Dynamic coalition formation and the core,” *Journal of Economic Behavior & Organization*, vol. 49, p. 363380, 2002.
[20] K. Akkarajitsakul, E. Hossain, and D. Niyato, “Coalition-Based Cooperative Packet Delivery under Uncertainty: A Dynamic Bayesian Coalitional Game,” *IEEE Transactions on Mobile Computing*, vol. 12, no. 2, pp. 371 – 385, Feb. 2013.