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Relay Aided Smart Meter to Smart Meter Communication in a Microgrid

S. N. Islam, M. A. Mahmud and A. M. T. Oo
School of Engineering
Deakin University, Geelong, Australia
Email:{shama.i,apel.mahmud,aman.m}@deakin.edu.au

***Abstract*—In this paper, a new approach is considered for relay aided smart meter to smart meter communication in a microgrid. In the considered framework, a group of smart meters (SMs) simultaneously exchange pricing data with each other for selling or purchasing energy. At the same time, another group of SMs forward load demand and generation information to the control centre as these are the most important states of microgrid for balancing power. The data exchange between SMs and from SM to control centre are aided by a multi-antenna wireless relay, which acts as the communication gateway for the SMs. For the considered system model, the error performance, a key indicator for the reliability of smart grid communication, is analytically derived at the SMs and at the control centre. The analysis indicates that the error performance at the control centre degrades if a large number of SMs communicate with the control centre simultaneously, while the error performance at the SMs does not degrade with increasing number of SMs exchanging data with each other. Finally, the analytically derived error performance is verified using numerical simulations.**

***Index Terms*—smart meter to smart meter communication, microgrid, wireless relay, error performance.**

I. Introduction

The ever increasing electricity demand due to rapid population growth along with the intricate nature of power distribution networks often causes inefficient operation of the traditional power grid and thereby, leading to massive network failures [1]. To improve the efficiency of the existing power grid, real-time monitoring and automation through effective communication between different components of the power system need to be ensured [2]. In this respect, smart grid has emerged as the solution incorporating two-way information exchange between utility and consumers [3]. Smart grids allow different functionalities such as remote meter reading, integration of distributed energy resources (DERs), demand side energy management, and detection of unauthorized usage to be incorporated in the power grid [2]–[4].

Recently, DERs have attained significant popularity in remote communities because the integration of these DERs in the smart grid allows households in a local community to meet their own load demand and supply excess energy either to other households in the community or to the main power grid. As a result, the households in the community form a transactive energy market through microgrids in which the energy selling or purchasing occurs among neighbours, as well as with the main grid [5]. For the meaningful operation of a microgrid, the load demand and generation data, along with the pricing information need to be shared in a timely manner among the households as well as among the households and the data aggregation unit (DAU)/gateway using smart meters (SMs).

The efficiency of exchanging information in a transactive microgrid depends on the communication technologies and these technologies are needed to fulfill some key requirements for smart grid communication, such as high reliability, large coverage, high security, and low latency [6]. There are different types of communication technologies which can mainly be based on either wireline (e.g., power line communication) or wireless (e.g., Wi-Fi) technologies [7]. Though wireline technologies can harness the benefits of existing residential wiring, their installation is less flexible than wireless communication technologies [2]. For this reason, the main emphasis is given on wireless communication technologies for smart grid communications in this paper.

So far, different types of communication protocols have been proposed in the literature to enable information exchange between the SMs and the DAU/gateway. The authors in [7] have considered a mesh connected network of SMs where these meters can forward their data through dynamically selected gateways. In [8], the authors considered an efficient SM message concatenation scheme to reduce network overheads caused by a large number of SMs. Some research papers have also focussed towards the performance analysis of smart grid communication in terms of power consumption and power supply costs [9], the delay performance [10], and packet error probability [11].

Recently, wireless cooperative relay-based communication [12] has gained significant research interests in the area of smart grid communication to introduce enhanced diversity and spectral efficiency in the power grid. In [13], a wireless relay station has been employed between DAU/gateway and the control centre to improve the information transmission rate. Different relaying strategies have been compared in [6] for smart grid communication in terms of spectral efficiency and coverage. The authors in [14] have jointly optimized power allocation and relay selection by considering idle SMs as relay nodes. In [15], smart relays have been introduced which can directionally forward the smart meter data to the desired DAU/gateway. Base station renewable energy cooperation to improve the throughput of the coordinated multi-point enabled mobile terminals has been investigated in [16]. The authors in

[17] proposed a device to device assisted relaying framework for energy management with improved spectral efficiency.

The above research works have considered data exchange between multiple SMs and between SMs and the control centre using time division multiple access (i.e., different SMs transmit data in different time slots). However, simultaneous data exchange among different SMs are required to improve the latency and spectral efficiency of smart grid communication, which allows to incorporate a larger number of SMs in the infrastructure. In this case, there will be huge interferences if all SMs simultaneously forward their data to the intended smart meter directly which will degrade the reliability of data communication in a smart grid.

Usually, SMs in the network send load demand and generation information to the control centre whereas the control centre detects the power mismatch and forms pairs of SMs who can overcome this mismatch by energy selling or purchasing to/from another SM in the pair. The selected pairs of SMs then exchange the pricing information within the pair to enable energy cooperation. In such a scenario, an efficient approach will be to allow a group of SMs to forward load demand and generation information to the control centre at the same time when another group of SMs exchange their pricing data with each other.

This paper is aimed to facilitate a multiple antenna relay aided smart meter to smart meter communication in a microgrid, where at a certain time instant, a group of SMs send their load demand and generation data to the control centre, whereas another group of SMs exchange pricing data with each other simultaneously, both aided by the relay. To the best of the authors' knowledge, the aforementioned approach for relay aided smart meter to smart meter communication has not been investigated in the literature yet. In this respect, the following contributions are made in this paper:

- A new approach for relay aided smart meter to smart meter communication is investigated for a microgrid to enable simultaneous information exchange between different SMs, as well as between SMs and the control centre, both through the relay. In this approach, minimum mean square error (MMSE) precoding at the relay is applied to separate out the intended data streams for the SMs and the control centre.
- For this relay aided smart meter to smart meter communication, the error performances at the SMs and at the control centre are analytically derived, which can serve as one of the main reliability indicators for smart grid communication.
- The analysis shows that the error performance degrades at the control centre with increasing number of SMs which are forwarding load demand and generation data to the control centre. It also shows that the error performance at the SM does not degrade with increasing number of SMs.

The rest of the paper is organized in the following manner. The system model for the relay aided smart meter to smart meter communication is presented in Section II. The signal transmission protocols are explained in Section III. The error performance analysis for communication between SMs, as well as for the communication between SM and control centre is performed in Section IV. The numerical simulation results have been provided in Section V to verify the analytical derivations. Finally, Section VI concludes the paper.

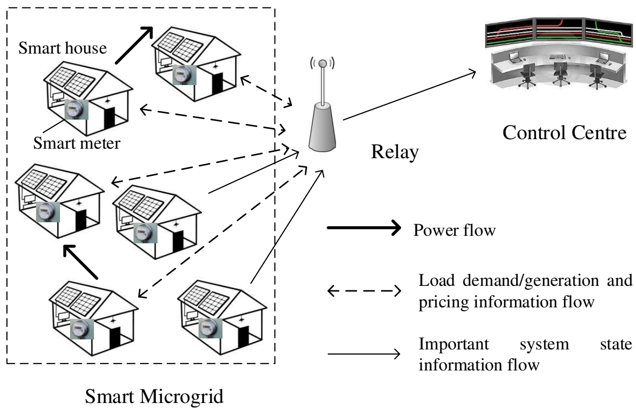


Fig. 1. System model for relay aided smart meter to smart meter communication in a smart microgrid where at a certain time instant, a group of SMs exchange the pricing information between each other, whereas another group of SMs forward load demand and generation information to the control centre.

II. System Model

We consider a residential area with L households connected to a smart microgrid, where at a certain time instant, the SMs in L_1 houses exchange the pricing data with the SMs of L_1 other houses to purchase/sell the excess energy. At the same time, the SMs in L_2 houses send load demand and generation data to the control centre, which then decides the indices of the pairs of households who can sell/purchase energy to/from each other. These indices are forwarded to the SMs and at the following time instant, these SMs can exchange their pricing data with each other, while another group of SMs forward their load demand and generation data to the control centre.

We assume that the SMs exchange data through a wireless relay node, which is capable of decoding the data from SMs and applying MMSE precoding to the decoded data signals so that each SM, as well as the control centre receives only the data intended for it. Here we consider that the wireless transceivers at the SMs and the relay are half duplex in nature. We also assume that all the SMs are equipped with single antenna, whereas the relay is equipped with M antennas, where $M > L$. The transmission power at the SMs and the relay for communicating different information are denoted by P_{sm} and P_r, respectively.

At a certain time instant, all the SMs indexed by SM_i exchange their pricing data with the SMs indexed by SM'_i. Here $i \in [1, L_1]$ is the index for the pair of smart houses that are selling/purchasing the energy, which is selected previously by the control centre based on the load demand and generation data from the smart meters. At the same instant, the SMs indexed by SM_j forward their load demand and generation data to the control centre, where $j \in [1, L_2]$. We denote the channel vector between the SM_i^{th} (SM'^{th}_i) SM and the relay as $\mathbf{h}_{sm_i,r}$ ($\mathbf{h}_{sm'_i,r}$)$\in \mathbb{C}^{1\times M}$, the channel vector between the SM_j^{th} SM and the relay as $\mathbf{h}_{sm_j,r} \in \mathbb{C}^{1\times M}$ and the channel vector between the control centre and the relay as $\mathbf{H}_{c,r} \in \mathbb{C}^{1\times M}$.

The channels are assumed to be block Rayleigh fading channels, which remain constant during a certain time slot. The channels in different time slots are considered to be independent. Moreover, reciprocity has been assumed for all the channels between SMs and the relay and also, for the channel between the relay and the control centre. The perfect instantaneous channel state information (CSI) of the overall network, i.e., perfect global CSI is available to the relay. The fading channel coefficients are zero mean complex-valued Gaussian random variables with variances $\sigma^2_{h^m_{a,r}}$ for the m^{th} ($m \in [1, M]$) entry of the channel vectors between node a and the relay, where $a \in \{c, sm_i, sm'_i, sm_j\}$.

III. Signal Transmission Protocols

A. Time Slot 1

At the first time slot, SMs associated with $2L_1$ households transmit their pricing data and the SMs associated with L_2 households transmit load demand and generation data simultaneously, whereas the relay receives the sum of the signals. Let us consider that SM_i^{th} and SM'^{th}_i SMs transmit signals $x_{d,i}$ and $x_{d',i}$ where $i \in [1, L_1]$. At the same time, all SM_j^{th} SMs transmit their signal as $x_{c,j}$, where $j \in [1, L_2]$. The relay receives the sum of the signals as follows

$$\mathbf{y}_r = \sqrt{P_{sm}} \sum_{i=1}^{L_1} (\mathbf{h}_{sm_i,r} x_{d,i} + \mathbf{h}_{sm'_i,r} x_{d',i}) + \sqrt{P_{sm}} \sum_{j=1}^{L_2} \mathbf{h}_{sm'_j,r} x_{c,j} + \mathbf{n}_r \quad (1)$$

where $\mathbf{n}_r \in \mathbb{C}^{M\times 1}$ is the zero mean complex additive white Gaussian noise (AWGN) vector at the relay with noise variance $\sigma^2_{n^m_r} = \frac{N_0}{2}$ per dimension for the m^{th} entry of the noise vector. Finally, the relay estimates the signals from SM_i^{th}, SM'^{th}_i and SM_j^{th} SMs as $\hat{x}_{d,i}$, $\hat{x}_{d',i}$ and $\hat{x}_{c,j}$ using maximum likelihood (ML) detector.

B. Time Slot 2

At the second time slot, the relay computes the sum of the signals from the SMs associated with each pair of households who want to exchange the pricing data along with the load demand and generation data. Then the relay concatenates the data from the SMs who want to forward information to the control centre[1]. Next the relay multiplies the sum of signals intended for a certain pair of SMs and the concatenated load demand/generation data intended for the control centre with appropriate precoding vectors such that only the intended SM or the control centre receive the data. Finally the relay broadcasts the resulting signal to the SMs and the control centre.

Let us consider that the relay computes the sum of signals decoded from the SM_i^{th} and the SM'^{th}_i SMs as $\hat{x}_i$ and multiplies it with the precoding vector $\mathbf{u}_{r,i} \in \mathbb{C}^{M\times 1}$ such that only SM_i^{th} and SM'^{th}_i SMs receive $\hat{x}_i$. To ensure this, the precoding vector for i^{th} pair of SMs must remain in the null space of the channel vector between other SMs and the relay, as well as the channel vector between the control centre and the relay. That is,

$$\begin{aligned} \mathbf{h}_{sm_b,r}\mathbf{u}_{r,i} &= 0 \quad b \in [1, L_1], b \neq i, \\ \mathbf{h}_{sm'_b,r}\mathbf{u}_{r,i} &= 0 \quad b \in [1, L_1], b \neq i, \\ \mathbf{h}_{sm_b,r}\mathbf{u}_{r,i} &= 0 \quad b \in [1, L_2] \end{aligned} \quad (2)$$

and

$$\mathbf{h}_{c,r}\mathbf{u}_{r,i} = 0 \quad (3)$$

Also, the relay concatenates the data decoded from the SM_j^{th} SM for all $j \in [1, L_2]$ to construct the data packet $\hat{x}_c$ and multiplies with precoding vector $\mathbf{u}_{r,c}$ such that only the control centre receives the data packet $\hat{x}_c$. For this, the precoding vector must lie in the null space of the channel between the SMs and the relay. Thus,

$$\mathbf{h}_{sm_b,r}\mathbf{u}_{r,c} = 0 \quad b \in [1, L] \quad (4)$$

Finally, the relay broadcasts the following signal:

$$\mathbf{x}_r = \sum_{i=1}^{L_1} \mathbf{u}_{r,\ell}\hat{x}_i + \mathbf{u}_{r,c}\hat{x}_c \quad (5)$$

The received signal at the SM_i^{th} SM is given as:

$$y_{d,i} = \sqrt{P_r}\mathbf{h}_{sm_i,r}\mathbf{x}_r + n_{d,i} \quad (6)$$

where $n_{d,i}$ denotes the zero mean complex AWGN at the SM_i^{th} SM with variance $\sigma^2_{n_{d,i}} = \frac{N_0}{2}$ per dimension. Using (5), (2) and (3), the received signal at the SM_i^{th} SM can be re-written as

$$y_{d,i} = \sqrt{P_r}\mathbf{h}_{sm_i,r}\mathbf{u}_{r,i}\hat{x}_i + n_{d,i} \quad (7)$$

Finally, the SM_i^{th} SM estimates the sum of signals as $\hat{\hat{x}}_i$ using ML detector, subtracts its own signal $x_{d,i}$ from $\hat{\hat{x}}_i$ to obtain the SM'^{th}_i SM's data.

Similarly, the control centre receives the signal at the second time slot as

$$y_c = \sqrt{P_r}\mathbf{h}_{c,r}\mathbf{x}_r + n_c \quad (8)$$

where n_c denotes the zero mean complex AWGN at the control centre with variance $\sigma^2_{n_c} = \frac{N_0}{2}$ per dimension. Using (4), (8) can be re-written as:

$$y_c = \sqrt{P_r}\mathbf{h}_{c,r}\mathbf{u}_{r,c}\hat{x}_c + n_c \quad (9)$$

Finally, the control centre estimates the concatenated load demand and generation data from L_2 smart meters using ML detector as $\hat{\hat{x}}_c$. Based on this concatenated data, the control centre determines the SM pairs for energy cooperation and

[1] The data packets from individual SM are usually small and concatenating these will not make the data packet too long. This approach is often adopted to reduce the network overhead in smart grid communication [8].

broadcasts the indices. According to these indices, the SMs exchange pricing data at the next time instant.

C. Optimum Precoder Design

The optimum precoding vector is designed at the relay to minimize the mean square error (MSE) at the SMs and the control centre. The MSE at the SM_i^{th} SM is written as:

$$\text{MSE}_i = E[||y_{d,i} - \hat{x}_i||^2] \tag{10}$$

Using (7), the MSE can be simplified to:

$$\text{MSE}_i = E[||\sqrt{P_r}\mathbf{h}_{sm_i,r}\mathbf{u}_{r,i} - 1||^2 + N_0] \tag{11}$$

Now, the optimum value of $\mathbf{u}_{r,i}$ is obtained by differentiating (11) with respect to $\mathbf{u}_{r,i}$ and setting the resulting value to zero. Thus, the optimum value is $\mathbf{u}_{r,i} = \frac{1}{\sqrt{P_r}||\mathbf{h}_{sm_i,r}||}$.

Similarly, the MSE at the control centre is $\text{MSE}_c = E[||\sqrt{P_r}\mathbf{h}_{c,r}\mathbf{u}_{r,c} - 1||^2 + N_0]$. The MSE at the control centre is minimized by differentiating it with respect to $\mathbf{u}_{r,c}$ and setting the resulting value to zero, which gives the optimum value as $\mathbf{u}_{r,c} = \frac{1}{\sqrt{P_r}||\mathbf{h}_{c,r}||}$.

IV. Error Performance Analysis

In this section, we investigate the error performance at the SMs for relay aided pricing data exchange, as well as at the control centre for relay aided load demand and generation data exchange. First, the signal to noise ratios (SNRs) are derived at the relay, at the SMs and at the control centre.

The SNR of the signal received from the SM_i^{th} SM at the relay is $\gamma_r = \frac{P_{sm}||\mathbf{h}_{sm_i,r}||^2}{N_0}$. Similarly, the SNR of the signal received from the relay at the SM_i^{th} SM is: $\gamma_{sm_i} = \frac{P_r||\mathbf{h}_{sm_i,r}\mathbf{u}_{r,i}||^2}{N_0}$. And the SNR of the signal received from the relay at the control centre is $\gamma_c = \frac{P_r||\mathbf{h}_{c,r}\mathbf{u}_{r,c}||^2}{N_0}$.

Using these SNR expressions, the error performance can be analyzed at the relay, SMs and the control centre. For the rest of this section, it is assumed that the SMs transmit binary phase shift keying (BPSK) modulated signals. Thus, the probability of incorrectly decoding the SM_i^{th} SM's data at the relay is:

$$P_e(r, sm_i) = Q\left(\sqrt{\frac{2P_{sm}||\mathbf{h}_{sm_i,r}||^2}{N_0}}\right) \tag{12}$$

The probability of incorrectly decoding the data of a SM at another SM who wants to exchange pricing data with this SM is given in the following lemma.

Lemma 1: The probability of incorrectly decoding the data of the $SM_i'^{th}$ SM at the SM_i^{th} SM is:

$$P_e(sm_i, sm_i') = (1 - (1 - P_e(r, sm_i))(1 - P_e(r, sm_i'))) \times (1 - P_e(sm_i, r)) + (1 - P_e(r, sm_i))(1 - P_e(r, sm_i'))P_e(sm_i, r) \tag{13}$$

where $P_e(sm_i, r)$ is the probability of incorrectly decoding sum of the signals from the relay at the SM_i^{th} SM.

Proof: The SM_i^{th} SM incorrectly decodes the data of $SM_i'^{th}$ SM in two possible cases: (i) if the relay correctly decodes the data of SM_i^{th} and $SM_i'^{th}$ SM (i.e., $\hat{x}_{d,i} = x_{d,i}$ and $\hat{x}_{d',i} = x_{d',i}$) and the SM_i^{th} SM incorrectly decodes the sum of the signals from the relay (i.e., $\hat{\hat{x}}_i \neq \hat{x}_i$) or (ii) if the relay incorrectly decodes the data of at least one of the SM_i^{th} and the $SM_i'^{th}$ SM (i.e., $\hat{x}_{d,i} \neq x_{d,i}$ and/or $\hat{x}_{d',i} \neq x_{d',i}$) and the SM_i^{th} SM correctly decodes the sum of the signals from the relay (i.e., $\hat{\hat{x}}_i = x_i$).

Now, the probability of correctly decoding the data of both the SM_i^{th} and the $SM_i'^{th}$ SM at the relay is:

$$\Pr(\hat{x}_{d,i} = x_{d,i}, \hat{x}_{d',i} = x_{d',i}) = (1 - P_e(r, sm_i))(1 - P_e(r, sm_i')) \tag{14}$$

Thus, the probability of incorrectly decoding at least one of the SM_i^{th} and the $SM_i'^{th}$ SM's data at the relay is $(1 - (1 - P_e(r, sm_i))(1 - P_e(r, sm_i')))$.

Similarly, the probability of incorrectly decoding the sum of the signals from the relay at the SM_i^{th} SM is:

$$P_e(sm_i, r) = Q\left(\sqrt{\frac{2P_r||\mathbf{h}_{sm_i,r}\mathbf{u}_{r,i}||^2}{N_0}}\right) \tag{15}$$

Putting altogether, the probability of incorrectly decoding the $SM_i'^{th}$ SM's data at the SM_i^{th} SM can be written as in (13) which completes the proof. ■

Now the probability of incorrectly decoding the system state data from the SMs at the control centre is provided in the following lemma.

Lemma 2: The probability of incorrectly decoding the data from L_2 SMs at the control centre is:

$$P_e(c) = \frac{1}{L_2}\sum_{j=1}^{L_2} P_e(r, sm_j)(1 - P_e(c, r)) + \left(1 - \frac{1}{L_2}\sum_{j=1}^{L_2} P_e(r, sm_j)\right) P_e(c, r) \tag{16}$$

where $P_e(c, r)$ is the probability of incorrectly decoding the concatenated data packet from the relay at the control centre.

Proof: After decoding all the load demand and generation data packets from L_2 SMs, the relay concatenates these L_2 data packets and broadcasts to the control centre. Thus, the probability of incorrectly decoding the concatenated data packet at the relay will be the average of the probabilities of incorrectly decoding each of L_2 data packets at the relay, which is given by $\frac{1}{L_2}\sum_{j=1}^{L_2} P_e(r, sm_j)$. On the other hand, the probability of incorrectly decoding the concatenated data packet from the relay at the control centre is:

$$P_e(c, r) = Q\left(\sqrt{\frac{2P_r||\mathbf{h}_{c,r}\mathbf{u}_{r,c}||^2}{N_0}}\right) \tag{17}$$

Now, the control centre will incorrectly decode the data packets from L_2 SMs in two cases: (i) if the relay incorrectly decodes the concatenated data packet and the control centre correctly decodes it (i.e., $\hat{x}_c \neq x_c$ and $\hat{\hat{x}}_c = \hat{x}_c$) or (ii) if the relay correctly decodes the concatenated data packet and the control centre incorrectly decodes it (i.e., $\hat{x}_c = x_c$ and $\hat{\hat{x}}_c \neq \hat{x}_c$). Based on this, the probability of incorrectly decoding the load demand and generation data packets from the L_2 SMs at the control centre is written as in (16), which completes the proof. ■

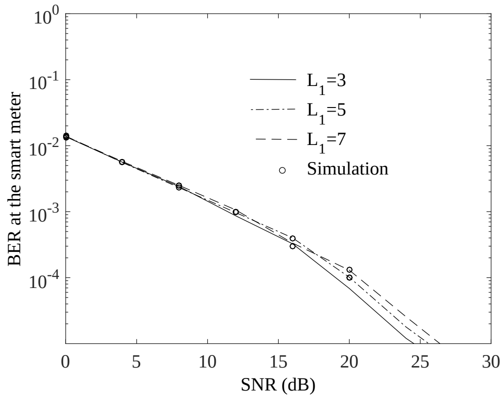
Remark 1: From (13), it can be noted that a SM can correctly decode the data of another SM to whom it is selling or from whom it is purchasing energy, if the communication channels from both of these SMs to the relay experience good conditions. Thus, increasing the number of SMs who share their pricing information with another smart meter will not degrade the error performance at the SMs. However, the computation complexity at the relay will increase as it will need more antennas. Also, from (16), it can be identified that with increasing number of SMs, the probability of correctly decoding the concatenated data packet decreases because the probability of correctly decoding data packets from a large number of SMs simultaneously will be less. This implies that at a certain time instant, a smaller number of smart meters can be allowed to share the load demand and generation data packets to the control centre. On the other hand, the SMs who want to share the pricing data can be placed in a queue and once sufficient number of SMs are in the queue, then these SMs are allowed to exchange pricing data.

V. Numerical Results

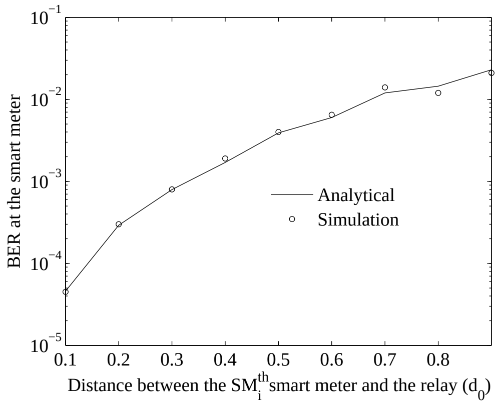
In this section, the numerical simulation results are provided to verify the error performance analysis as presented in Section IV. Different microgrids are considered with $L_1 = 3, 5, 7$ smart houses who share their pricing data with L_1 other smart houses through the relay along with $L_2 = 4, 8, 12$ smart houses who forward load demand/generation data to the control centre through the relay. The average channel gain between node a and the relay is modeled as $\sigma^2_{a,r} = (\frac{1}{\frac{d_{a,r}}{d_0}})^{\nu}$, where $a \in \{SM_i, SM'_i, SM_j, c\}$, $d_{a,r}$ is the distance between node a and the relay which is uniformly distributed between 0 and d_0, with d_0 as the reference distance and $\nu = 3$ is the path loss exponent. The simulation results are averaged over 100 time frames.

Figures 2(a) and 2(b) show the error performance at the SM_i^{th} SM for different numbers of SMs who share their pricing data and for different distances between the SM_i^{th} SM and the relay, respectively. The analytical results in these figures have been plotted using (13). From Fig. 2(a), it can be seen that the error performance at the SM_i^{th} SM does not depend on the number of users as the precoding vector at the relay is designed in such a way that each SM receives only the data intended for it. From Fig. 2(b), it is clear that if the SM_i^{th} SM has a larger distance from the relay, the error performance at the SM will degrade due to poor channel conditions between the SM and the relay.

Figures 3(a) and 3(b) show the impact of different number of SMs who forward load demand/generation data to the control centre and the impact of the maximum distance between the SM_j^{th} SM and the relay, respectively on the error performance



(a) Impact of number of smart meters

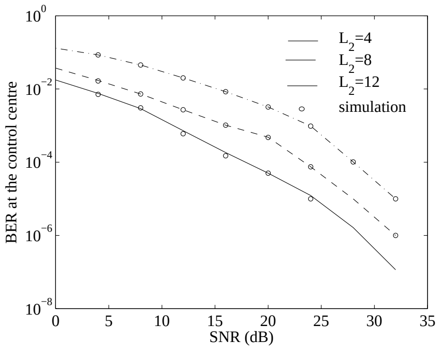


(b) Impact of distance

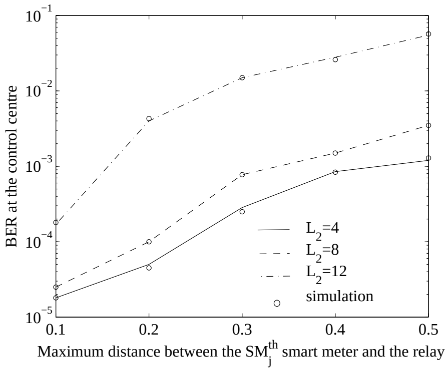
Fig. 2. Error performance for relay aided data exchange between different smart meters.

at the control centre. To obtain these figures, it is considered that the distance between the control centre and the relay is fixed at $0.5d_0$ and the distance between the SM_j^{th} SM and the relay is distributed between 0 and $0.5d_0$. That is, the SMs are closer to the relay than the control centre. The analytical results in these figures are plotted using (16). From Fig. 3(a), it can be identified that with the increasing number of users, the error performance at the control centre degrades which is expected from (16). Fig. 3(b) demonstrates that if the maximum distance between the SM_j^{th} SMs and the relay is larger, the error performance at the control centre degrades. This occurs as the poor channel conditions between a certain SM and the relay lead to increasing error probability at the relay for that SM. The increasing error probability at the relay also increases the probability of incorrectly decoding the concatenated data packet at the control centre.

Fig. 4 shows the error performance at the control centre for two cases: (i) when the distances of 90% SMs from the relay are larger than $0.4d_0$ (i.e., the channel conditions between most of the SMs and the relay are poor) and (ii) when the distances of 90% SMs from the relay are smaller than $0.1d_0$ (i.e., the channel conditions between most of the SMs and the relay are better). Note that when most of the SMs are



(a) Impact of number of smart meters



(b) Impact of distance

Fig. 3. Error performance for relay aided load demand/generation data exchange between smart meters and the control centre.

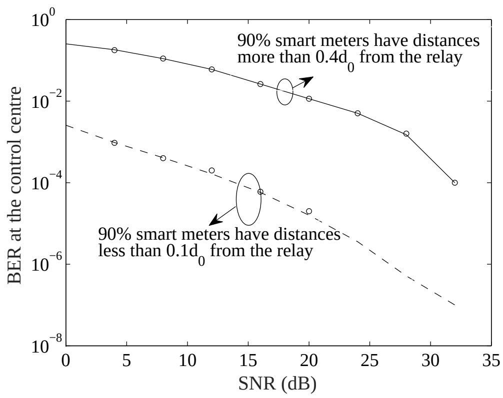


Fig. 4. Error performance at the control centre for the cases (i) when 90% smart meters have distances larger than $0.4d_0$ from the relay and (ii) when 90% smart meters have distances smaller than $0.1d_0$ from the relay.

closely located to the relay, the error performance improves significantly, compared to the case when most of the SMs have larger distances from the relay.

VI. Conclusions

In this paper, the error performance of a smart microgrid is studied, where a group of SMs exchange their pricing data to each other simultaneously. At the same time, another group of SMs forward load demand and generation information to the control centre. Both these information exchanges are aided by a multi-antenna relay. For such a system, the error performances are analyzed at the SMs and at the control centre. The analysis shows that when more SMs forward load demand and generation data to the control centre, the error performance degrades. However, for increasing number of SMs exchanging pricing data to each other, the error performance does not degrade and this is achieved at the cost of more antennas at the relay. Our future work on smart meter to smart meter communication will focus on the load demand and generation information exchange among the SMs directly without involving the control centre.

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