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The impact of transmission error on the performance of cooperative wireless transmission on smart metering environment

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Abstract

Recently, the Smart Grid Network (SGN) has received considerable attention. SGN offers several and innovativetechnologies to make efficient and intelligent grid systems. The SG architecture includes several communication schemes to ensure the best power transmission and meet the needs of the consumer. Thus, there are many challenges that making the transmission as a difficult task, especially the wireless communication. In reality, wireless transmissions are error-prone and transmission errors which can lead to a mismatch on the power supply information exchange. This paperaims to suggest a quickly andsimultaneous model called Cooperative Wireless Transmission for Smart Metering (CWT). First, the purpose is to estimate the total power of all consumers and satisfy the peak power constraints. Furthermore, we study the impact of the channelerror on the performance of CWT system. In our analysis, we assume that the complex fading channel coefficients are estimated at the transmission levels with errors. The CWT scheme is evaluated in terms of Cooperative Symbol Error Rate (CSER). Simulations results shows that CWT mechanism achieve the satisfying results.

*Keywords:*Smart Grid, Cooperative, Wireless Communication, Power Supply,Channel Error, CSER

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1. Introduction

Today's, the power grid needs ought to progress quickly and gradually. So, to satisfy the consumer's need and adjust the power management, the need for integration of Smart Grid (SG) becomes a necessary solution since it fulfill these requirements. The efficiency and reliability of power generation and distribution are required, so that is to keep the power system monitoring with real time [1]. Nevertheless, there are several challenges in the implementation of a reliable SG network including the estimation of power supply in advance which is the objective of this paper. Furthermore, the ability to forecast the load requirement is a powerful tool for the management of power systems. In addition, the reliability of communication links is also a challenging task in the wireless transmission especially for SG. So, the quality of transmission and reliability of the network must be ensured. To reach a good performance in terms of quality of forecasting power, the transmission error is forbidden and high reliability is required. Nevertheless, due to various radio propagation issues, the power outage can be occurred.

In practice, it is difficult to get perfect Channel State Information (CSI) due to delayed feedback or channel estimation errors, which reflects the degradation of the system performance. As a result, simultaneous and cooperative transmission is required in order to obtain a good transmission.

Many works have been done in the field of cooperative wireless transmission with channel estimation error. In [2] by adopting a new mechanism of relay selection with outdated CSI in Two way relaying (TWR), the closed form approximation for outage probability has been derived. The studies of paper [3] designed a model in two-way AF multiple relay to review the impact of CSI on single relay selection andminimize the outage probability or BER. To evaluate the outage probability and error probability, the authors in [4] have studied the performance of AF TWRN with the presence of channel estimation error. The impact of outdated CSI on the secrecy outage performance has been investigated on[5].

All the work performed has considered the analysis of cooperative transmission and relay selection under imperfect CSI in general way. This paper is therefore devoted to analyze the performance of Cooperative Wireless Transmission for Smart Metering (CWT) with imperfect CSI. Our main contribution is to evaluate the total estimated power of all consumers by considering the channel error. An analysis in terms ofCooperative Symbol Error Rate (CSER) is given. Furthermore, an evaluation in term of Estimated Power (EP) is established. Then, this paper is organized as follows. Section II describes the model of system. Section III , we introduce the Cooperative Wireless Transmission under channel estimation error. In section III, Simulation results are presented and discussed. A conclusion of this paper is given in Section IV.

2. System Model

The system model under consideration is shown in Fig. 1. Several group of Neighbor Area Network (NAN) are connected to the Data Aggregation Point (DAP) via smart meter. The aim is to transmit the total power from all consumers so that to satisfy it in time and estimate it in the next time under the channel estimation error. In wireless transmission, the multipath fading can severely degrade the performance of the transmitted signal. To describe the status of the channel system, we chose the Nakagami fading for the reason that is general model for different fading environment. In addition to that, it's flexibility and accuracy make it greater than other channel models.[6], The transmitted signal represents the total power of all consumers. The communication between the DAP and all consumers is established via wireless link. To simplify,we focus our study only for one group of neighbors, but the analysis can be extended to a large set of NAN.

The received signal can be represented as:

$$y = \sum_{i=1}^{N} x_i \, \hat{h}_i + n \tag{1}$$

where x_i represents the power demand for one consumer. n is a complex zero-mean white Gaussian random process with σ_N^2. The fading coefficients $h_i$are zero-mean complex Gaussian random variables.

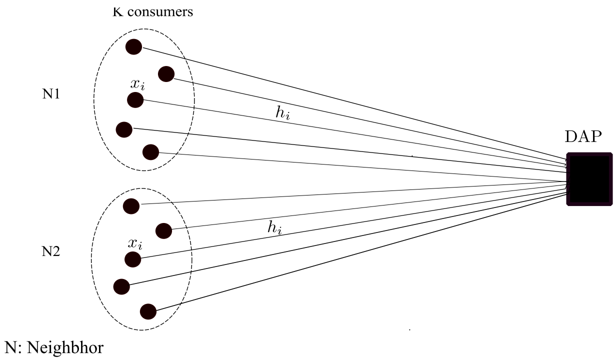

Fig. 1. System Model .

3. Cooperative wireless transmission

In our previous work [7], a Cooperative Wireless Transmission of Smart Metering called (CWT) is proposed to improve the transmission quality by reducing transmission errors and time delays. The objective is to gather the total of power consumption demand from every consumer and convey it simultaneously through a DAP to the control center. In fact, the first frequency (f0) is allocated to the control center to broadcast the pilot symbols, only one time, to all users for the estimation of the channel state information (CSI). Nevertheless, due to the channel error, there is a chance that the transmission will fail. So, in this paper, we analyze the impact of imperfect channel estimation on the performance of CWT scheme.

3.1. Synchronization Process

To keep the transmission cooperative and simultaneous, we propose for our model to utilize the TV White Spectrum (TVWS) to ensure the synchronization between all users. First, the CC communicates with a TVWS Database (WSDB) to utilize unused spectrum and exploits the available spectrum so that different consumers could connect to it. The WSDB contains a geolocation database that can enable white space spectrum to the CC. After that, each set of K consumers can share the same frequency. For instance, as depicted in Fig .2, the node 1 and node 2 get respectively frequency f1 and f2. The detection procedure of vacant channel is out of scope of this paper.

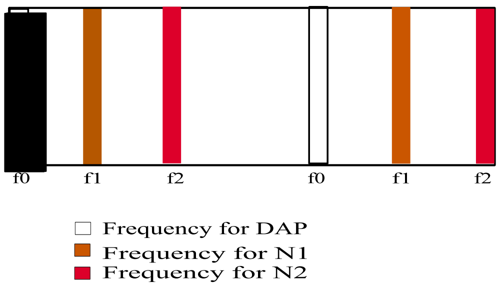

Fig. 2. Synchronization Process

3.2. CWT Under Channel Error

In SG environment, the information about power demandneeds to be known and estimated correctly. However, inwireless communication the knowledge about the channel is not perfect and the channel state information (CSI) is limited. In the first phase, the DAP broadcasts the pilot symbols with the estimated channel h_i. After that, each consumer i transmits his own data multiplied by the inverse of h_i.

From (1), we can reformulate the expression of the received signal as :

$$y = \sum_{i=1}^{N} \frac{x_i {h_i}^*}{\|h_i\|^2} \hat{h}_i + n \qquad (2)$$

Assuming the orthogonality between the channel estimate and the estimation error, the following relation can be obtained:

$$\hat{h} = h + e \qquad (3)$$

Which leads us to:

$$y = \sum_{i=1}^{N} x_i \frac{h_i {h_i}^*}{\|h_i\|^2} + \sum_{i=1}^{N} x_i \frac{{h_i}^* e_i}{\|h_i\|^2} + n \qquad (4)$$

Finally we have:

$$y = \sum_{i=1}^{N} x_i + \sum_{i=1}^{N} x_i \frac{{h_i}^* e_i}{\|h_i\|^2} + n \qquad (5)$$

Where the channel coefficients h_i is supposed to be independent and distributed as $CN(0,\sigma_h)$. The additive noise n is also distributed as $CN(0,\sigma^2)$,and e is the channel estimation errors which is distributed as $CN(0,\sigma_e^2)$ where σ_e^2=E[$|\hat{h}|^2$]-E[$|h|^2$]. Therefore, h_i is also distributed as $CN(0,\sigma_h+\sigma_e^2)$

The received signal can be decomposed into the message part$\sum_{i=1}^{N} x_i$, the noise and error parts $\sum_{i=1}^{N} x_i \frac{{h_i}^* e_i}{\|h_i\|^2}+n$ By using the properties of the product of variance of independent random variables. The total noise power is

defined as :

$$N_{tot} = \sum_{i=1}^{N} \mathrm{E}(x_i^2)\sigma_e^2 \,\mathrm{E}\left(\frac{{h_i}^*}{\|h_i\|^2}\right) \qquad (6)$$

4. Estimated Power Treatment

Each smart meter (SM) contains the information about the value of the power in each house. We denote the consumption power of all appliances in each house $i$by P_i. The received power at the level of the CC is given by:$P_t=[P_1......P_N]$.To send the powerP_i, which is analog, a treatment should be operated. First, we applied a quantization of 2^8levels and a step $p_u$on P_i to get a determined number of the power to transmit. After that, we proceeded with the coding of the quantization levels to get the binary vectors $b_i$as shown in the Fig.3.Also, we modulated each $b_i$with a Binary Phase Shift Keying (BPSK) modulation. BPSK has a good noise and interference resistance and immunity. At the reception, we obtain the total power of all consumers. According to Fig. 3, each element of the vector $\sum_{i=1}^{N} b_{ij}$refers to the sum of the BPSK modulated symbols. Each sum is a combination of the transmitted bits that depends on the number of consumers. For instance, if we have N users that transmit -1 at the same time, then $\sum_{i=1}^{N} b_{ij}$equals -N.

So as to estimate the received power P_t , according to the step p_u, we will have thisexpression,

$$P_t = \sum_{j=1}^{8} \sum_{i=1}^{N} b_{ij} \,.\, 2^{j-1} p_u \tag{7}$$

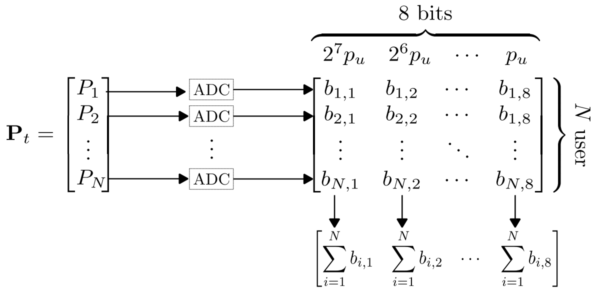

Fig. 3. The transmitted power treatment process

4. Probability of error

In this subsection, we analyze the proposed CWT scheme in terms of the probability of error (PER). As mentioned before, the h_i, e_i, $n$are all independent.

$$\text{Let Put} \begin{cases} P_i = \mathrm{E}(\sum_{i=1}^{N} x_i^2) \\ H = \mathrm{E}\left(\frac{h_i}{\|h_i\|^2}\right) \\ \sigma_t = H \cdot P_i \cdot \sigma_e \\ v_k = \sum_{i=1}^{N} x_i \end{cases}$$

Since the received value are not equiprobable, The formula of the Decision Boundaries (Dk) is calculated according to σ_t, then we have:

$$D_k = \frac{d}{2} + \frac{(\sigma_n^2 + \sigma_t^2) \ln \left(p(v_k) / p(v_{k+1}) \right)}{d} \tag{8}$$

The total value of the error probability with non-equal decision regions is then given by: [7]

$$\mathrm{PER} = \sum_{i=-N}^{N} p(v_k) . \sum \int_{D_k}^{\infty} p(\, y | v_k) dy \tag{9}$$

Where $\int_{D_k}^{\infty} p(y|v_k) = \mathrm{PER}_k$ denotes the error probability of the received values for CWT scheme. The noise adopted is an Additive Gaussian Noise and PER_k has a normal distribution with variance σ_n. This leads us to a more simplified error probability expression,

$$\mathrm{PER_k} = \mathbb{Q}\left(\frac{\mathrm{D_k}}{\sqrt{\sigma_n^2+\sigma_t^2}}\right) \quad (10)$$

For the extremities, the probability of error on the value $v_k$equals to:

$$\mathrm{PER_k} = \int_{D_k}^{\infty} p(y|v_k) = \mathbb{Q}\left(\frac{\mathrm{D_k}}{\sqrt{\sigma_n^2+\sigma_t^2}}\right) \quad (11)$$

For the intermediate values, the error probability is calculated at the right and the left of the received valuev_k. Then we have:

$$\mathrm{PER_k} = \int_{-\infty}^{v_{k-1}+D_{k-1}} p(y|v_k)dy + \int_{v_k+D_k}^{+\infty} p(y|v_k)dy = \left[1-\mathbb{Q}\left(\frac{v_{k-1}+D_{k-1}-v_k}{\sqrt{\sigma_n^2+\sigma_t^2}}\right)\right] + \mathbb{Q}\left(\frac{v_k+D_k-v_k}{\sqrt{\sigma_n^2+\sigma_t^2}}\right) \quad (12)$$

Using (11) and (12), the average probability of error under channel error is then equals to:

$$\mathrm{CSER} = \sum_{k=1}^{N-1} 2\cdot p(v_k)\cdot\left[\mathbb{Q}\left(\frac{d-D_{k-1}}{\sqrt{\sigma_n^2+\sigma_t^2}}\right)+\mathbb{Q}\left(\frac{D_k}{\sqrt{\sigma_n^2+\sigma_t^2}}\right)\right] + 2\cdot p(v_N)\cdot\mathbb{Q}\left(\frac{D_N}{\sqrt{\sigma_n^2+\sigma_t^2}}\right) \quad (13)$$

$$Where\begin{cases} D_N = D_{-N} \\ d = v_k - v_{k-1} \\ \mathbb{Q}(v_k) = 1-\mathbb{Q}(-v_k) \end{cases}$$

In the case of N even, a term depending on zero symbols should be added to (13). So, the total value of the probability of error is written as,

$$\mathrm{CSER} = p(v=0)\cdot\left[\mathbb{Q}\left(\frac{d-D_1}{\sqrt{\sigma_n^2+\sigma_t^2}}\right)+\mathbb{Q}\left(\frac{D_0}{\sqrt{\sigma_n^2+\sigma_t^2}}\right)\right]\cdot\sum_{k=1}^{N-1} 2\cdot p(v_k)\cdot\left[\mathbb{Q}\left(\frac{d-D_{k-1}}{\sqrt{\sigma_n^2+\sigma_t^2}}\right)+\mathbb{Q}\left(\frac{D_k}{\sqrt{\sigma_n^2+\sigma_t^2}}\right)\right] + 2\cdot p(v_N)\cdot\mathbb{Q}\left(\frac{D_N}{\sqrt{\sigma_n^2+\sigma_t^2}}\right) \quad (14)$$

5. Simulation Results

In this section, some numerical results are provided for illustrating our theoretical analysis. We consider a smart neighbor where the CC gathers the total power of all consumers. The number of users considered is 2 consumers and one DAP, justto simplify but the analysis can be extended to a large number of N. The modulation scheme in the transmission is the BinaryPhase Shift Keying with AWGN channel. The channel gains are considered steady for the duration of transmission. In our simulations, we analyze the proposed system by taking in the consideration that the transmission is perfect at the estimation on one time and imperfect on the other.

The following table presents different parameters adopted for the transmission:

Number of samples	105
Number of coding bits	8
Levels of quantization	2n
Maximum level of quantization	12
The parameter of fading m1	0.8
The parameter of fading m2	0.6
Omega Nakagami fading	1

Table 1. Simulation Parameters

Refers to (14) The Cooperative Symbol Error Rate (CSER) performance under channel error is evaluated. In Fig 4, 5, we investigate the accuracy of our analytics results by approaching them with simulation. The obtained results show that even if the sigma error increases, the CWT scheme achieves better results in term of Cooperative Symbol Error Rate. Fig 6shows a comparison between TDMA and CWT in terms of Power Metering Delay (PMD). PMD refers to the necessary time for the DAP to determine the value of the next power consumption. Since multiple users could transmit at the same time in our model, the same noise that is added to each signal in TDMA, is added, in our case, to all users, thus reducing the delay.

Another advantage of the proposed scheme is presented on Fig 7 and 8. The figures show a comparison of the EP with and without error for different value of SNR. The EP has some fluctuation when σ_e increases with an SNR equals to 8dB. So, a technicalaverage can be done in order to reach the best performancein EP. From the same figures and by employing an average SNR of 12dBfor different value of , the EP has significantly improved. This means that CWT still performed despite of the impact of channel estimation error. Thus, our mechanism keeps the reliability of transmission avoiding loss of power supply.

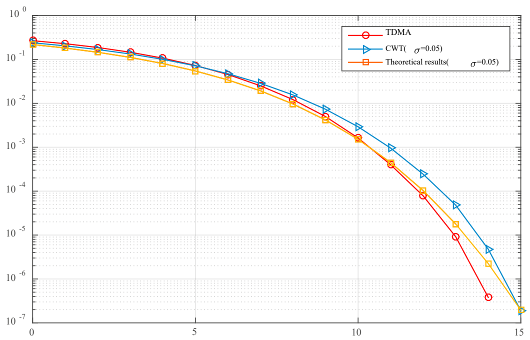

Fig 4. Average CSER of the cooperative transmissions underChannel error with the variance of the error is fixed as $\sigma_e = 0.05$

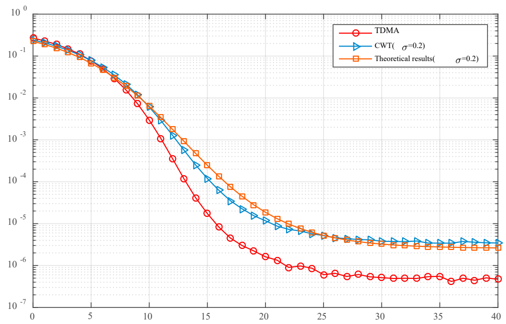

Fig 5. Average CSER of the cooperative transmissions underChannel error with the variance of the error is fixed as $\sigma_e = 0.2$

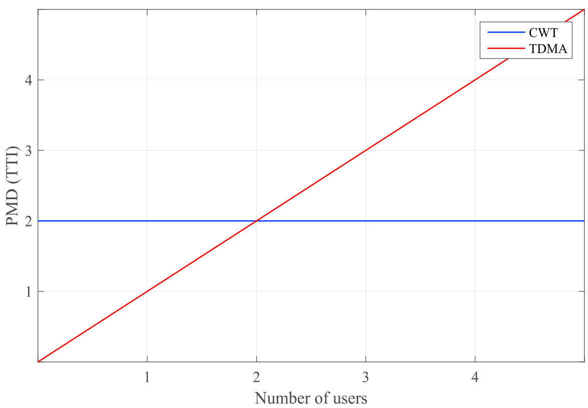

Fig. 6. Transmission duration for TDMA and CWT schemes

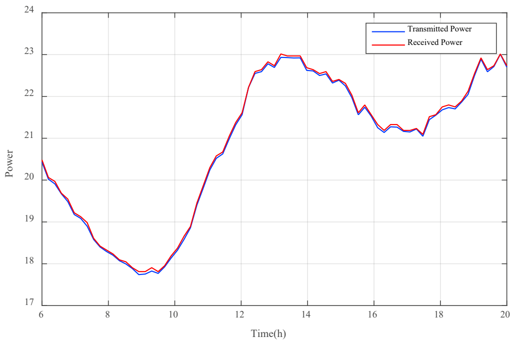

Fig. 7.Comparison of Transmitted and Received power under channel error with the variance of the error fixed as $\sigma_e = 0.05$and $\mathrm{SNR} = 12\mathrm{dB}$

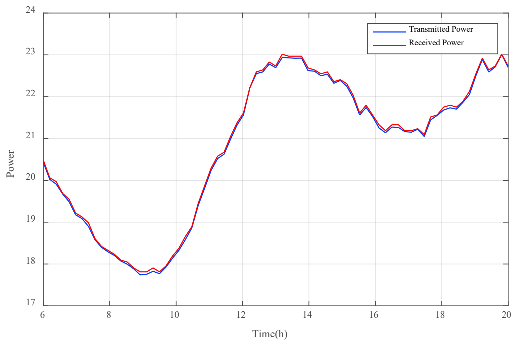

Fig. 8.Comparison of Transmitted and Received power under channel error with the variance of the error $\sigma_e = 0.2$ fixed and $\mathrm{SNR} = 12\mathrm{dB}$

6. Conclusion

In this paper, the impact of channel error on the Cooperative Wireless Transmission has been investigated. The purpose is to estimate the total power of all consumers under imperfect CSI by using CWT scheme. Moreover, the exact expression of CSER has been determined. Thus, in various value of sigma error, our approach has been verified to acquire the best performance for CWT. Also, the cooperative of our scheme make the system more resistive despite of the channel estimation error. For, the noise is divided on all consumers which make it protected from errors.

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