

Power Management for Collaborative Microgrids

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Abstract—Microgrids integrating green energy receive more attention from consumers since they present significant benefits including the ability to rely on more localized sources of power generation and keeping the environment healthy and safe. Thus, neighborhoods/cities opt for providing energy from green resources. However, the integration of renewable energies could lead to certain problems such as the destabilization and destruction of the power grids. For this reason, it is essential to build a robust management system and efficient communication between microgrids devices. This paper proposes a new approach based on a dynamic assignment of renewable energy tokens (DARET) algorithm and investigates a non-uniform hierarchical modulation as a data transmission technique over wireless channels. The proposed algorithm allows residential microgrids of a small geographic area to dynamically collaborate and share their individual green energy generation in order to supply their overall loads. The sharing is dynamically updated in short-term by exchanging data, in terms of individual demands and supplies, between the consumers over wireless links.

Index Terms—Collaborative Micro-Grid, Renewable Energy, Dynamic Power Management, Non-Uniform Hierarchical 16-QAM, Wireless Communication.

I. INTRODUCTION

Recently, the interest in microgrids has been growing as a new eco-friendly energy grid in order to avoid the increasing environmental pollutions caused by fossil fuel emissions. Thus, sustainability becomes an imperative requirement in electrical field. Generally, the microgrid can be defined as a small electrical grid formed by renewable sources, conventional generation, energy storage devices, power conversion systems and different controllers with advanced communication features. The microgrid can work in both connected and islanded mode [1].

Many studies have been investigated to manage power in microgrids operating. In [2], a dynamic assignment of renewable energy tokens algorithm is developed in order to add a smart collaborative behavior to a group of microgrids. The proposed scenario is an islanded microgrids model which collaborate with the power provided from their individual green energy sources. The role of this algorithm is to manage power sharing and to maintain, at the same time, the power balancing in the microgrids system. In [3], the non-uniform hierarchical 16-quadrature amplitude modulation technique is investigated to exchange information between different manager at all stages in smart grid. In [4], an optimization method is applied to minimize energy losses, production cost and carbon emissions in microgrid. Another study of power flow management is developed in [5] based on predictive control to reduce the disparity between demand curve and generation curve. In [6], the microgrid power is balanced by modifying the set-value of the grid voltage amplitude at the inverter ac-side according to changes of the dc-bus voltage of the DGs.

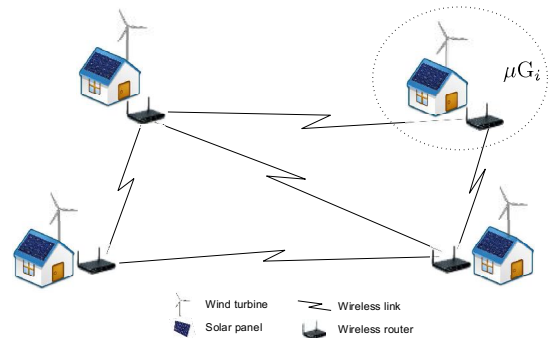


Fig. 1: Microgrids Architecture Scenario

This paper presents a dynamic assignment of renewable energy tokens algorithm, based on the schedulability of heavy loads and the individual green energy generation of each microgrid, especially photovoltaic and wind sources. The goal behind this algorithm is to manage the energy distribution of the whole system in order to maintain the power balancing in a smart collaborative aspect. Each microgrid is equipped by smart control panel (SCP) allowing the control of energy consumption behavior via load controllers (LCs). For the proposed approach, required data are transmitted within a wireless infrastructure based on a non-uniform hierarchical 16 quadrature amplitude modulation technique which protects differentially the exchanged information between SCPs and that depending to the importance of each one in power balance of the whole system.

The reminder of this paper is structured as follows. Section II describes a global architecture of the collaborative system of microgrids and develops the proposed DARET algorithm. Section III presents the non-uniform hierarchical 16-QAM. Section IV presents the performance results of the proposed approach while Section V concludes this work.

II. COLLABORATIVE SMART MICROGRIDS

The cost of renewable energy source (RES) technology and its deployment is still expensive. Thus, the collaboration of a number of microgrids with smaller and cheaper RESs can supply heavy loads, at the same time, allow a participant to be supplied even if its own system is down. Such collaborative system request an efficient communication infrastructure to communicate information between them as shown in Fig.1.

A. System description

Fig. 2 shows the intra-structure of each microgrid. It has two kind of supplying: independent part which supplies non-schedulable loads via the battery and collaborative part which supplies schedulable loads in interconnected grid. The latter are classified into controllable and non controllable loads. We define here the following load classes:

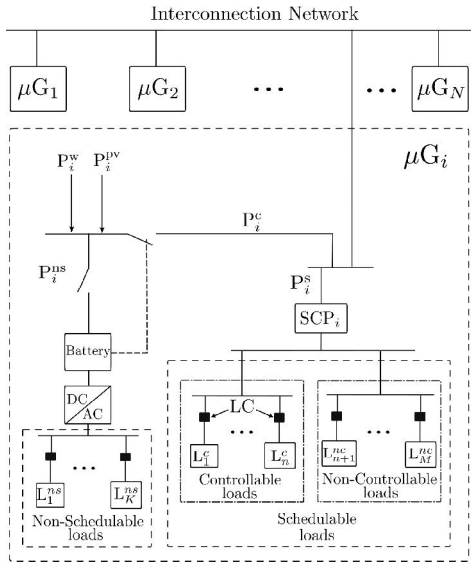


Fig. 2: Electrical power distribution

- *Non-Schedulable loads* are loads that we cannot determine its turning on and turning off because they present a paramount need and depend extremely in random behavior of users. Such as lighting, computer, fridge, etc.
- *Schedulable loads* are the electrical equipments that are time unconstrained and for which a user can prioritize. Within this category, we distinguish two sub-classes:
 - *Controllable loads* can be switched on or off through the LCs depending on the available power production. They include electrical equipment that can not be damaged if we turn them off during their operation such as air conditioning, etc.
 - *Non-controllable loads* can be switched on but cannot be switched off before the end of their operating time such as washing machine, etc.

We note that the schedulable loads present heavy loads which required significant power compared to non-schedulable loads consumption.

We suppose that we have a number N of residential microgrid having each one, up to, a number M of schedulable loads to be supplied by the interconnected grid. Each load has a downstream LC allowing its turning on and turning off depending on SCP decision. To keep balance power in this system, we have to check, in real time, the equality in (1).

$$\sum_{i=1}^N P_i^c = \sum_{i=1}^N P_i^s + P^{\text{loss}}, \quad (1)$$

where P_i^c (2) is the contribution power, P_i^s (3) is the consumed power for supplying the all schedulable loads (controllable and non-controllable loads), P^{loss} is the total loss power in electrical lines and the dissipated surplus power on dump loads (dissipating resistor).

$$P_i^c = P_i^w + P_i^{\text{pv}} - P_i^{\text{ns}}, \quad (2)$$

and,

$$P_i^s = \sum_{j=1}^n L_j^c + \sum_{j=n+1}^M L_j^{\text{nc}}, \quad (3)$$

where P_i^w is the photovoltaic power generation, P_i^{pv} is the wind power generation and P_i^{ns} is the consumed power for supplying non-schedulable loads of μG_i . L_j^c and L_j^{nc} , $j = 1, \dots, n$, are the consumed power by controllable and non-controllable loads, respectively.

In this study, we neglect losses in electrical lines and we consider $P^{\text{loss}} = P^{\text{dl}}$, P^{dl} is the dissipated power on dump loads. This power is less than the minimum requested one which is equivalent to one token.

Then, we must control one of the two generated and/or consumed powers to ensure this equality. Since production from intermittent sources is uncontrollable and is very dependent on climatic variation, we propose to push the power demand to be manageable.

We assume that we have a variation $\delta P_c = \sum_{i=1}^N \delta P_i^c$ of generated power, then we must vary the demand accordingly by $\delta P_s = \sum_{i=1}^N \delta P_i^s$.

Each microgrid is equipped by one SCP and many LCs. In fact, the LC measures the instant consumed power in order to send it to the SCP. Moreover, it relies on the SCP decisions to switch on or switch off the connected load. The SCP is the general controller in each microgrid, it is designed to collect all the power consumption information sent from LCs of the same microgrid, the contribution power, the priorities loads (R vector) and the total consumed power from the neighbors SCP. We opt for running the algorithm at each SCP in order to ensure a great redundancy and reduce the time of decisions broadcasting. Besides, it executes the DARET algorithm to make decisions about the consumption behaviour of the whole loads. After the SCP sends the decision to the appropriate LC in order to switch on or off the load.

B. Operation algorithm

We propose integrating the DARET algorithm at the SCP of each microgrid. We keep in SCPs data about the maximum consumed power by all schedulable loads. Power data is represented in terms of token unit equivalent to one kilowatt. We assume that the SCP is able to have forecasts curve of its own contribution power. Each SCP is equipped by wireless network interface card making it able to communicate with LCs and with the other SCPs. On one hand, the transmitted information intra-microgrid, between a SCP and LCs is done over bidirectional dedicated wireless channels. On the other hand, the transmitted information inter-microgrids between SCPs is done over shared channel.

The consumer of each residential microgrid sets on its local SCP its preferences in terms of needed loads to be turned on during 24 hours and their priorities (R vector). After exchanging these information within the collaborative system. Each SCP runs DARET algorithm, as presented in Algorithm 1, and sends its decisions of turning on or off to its schedulable loads.

Since, this collaborative system is based on the exchanging of several information to ensure the power balance within the microgrids system. Thus, it is primordial to ensure a good communication between all the entities of the proposed grid model. In the following section, we propose a modulation technique which is modeled to transmit simultaneous data-classes where a high protection priority is given to the critical information.

Algorithm 1 Dynamic Assignment of Renewable Energy Tokens

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1: INPUT: Maximal load power vector  $P^{\max}$ , Operating
   time vector  $T$ , Requested load priorities matrix  $R$ , Number
   of microgrids  $N$ , Number of loads per microgrid  $M$ ,
   Forecast individual contribution power  $P^c$ .
2: OUTPUT: Binary decision matrix  $D = \{d_{i,j}\}_{i,j=1}^{N \times M}$ .
3: PROCEDURE:
4:  $P^{\max} \leftarrow [P_{L_1}, P_{L_2}, \dots, P_{L_M}]$ 
5: Initialization of the Checking Matrix  $C = \mathbf{0}^{N \times M}$ 
6:  $n \leftarrow 0$ 
7: while  $C \neq \mathbf{1}^{N \times M}$  do
8:    $n \leftarrow n + 1$ 
9:    $P^D = \sum_i^N (P_i^c(n) - P_i^s(n))$ 
10:  while  $P^D < 0$  do
11:    Switch off the last controllable load  $m$ 
12:    Record the remaining operating time for load  $m$ 
13:     $P^D = P^D + P_{L_m}$ 
14:     $m \leftarrow m + 1$ 
15:  end while
16:  for  $j = 1$  to  $M$  do
17:    for  $i = 1$  to  $N$  do
18:       $k \leftarrow r_{i,j}$ 
19:      if  $c_{i,k} = 0$  and  $P^D - P_{L_k} \geq 0$  then
20:         $c_{i,k} \leftarrow 1$ 
21:         $d_{i,k} \leftarrow 1$ 
22:         $P^D \leftarrow P^D - P_{L_k}$ 
23:      end if
24:    end for
25:  end for
26: end while

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III. NON-UNIFORM HIERARCHICAL 16-QAM

In this paper, we propose to use a non-uniform hierarchical modulation 16-QAM [7] technique which can provide a reliable and effective transmission of different data-classes. In fact, it can guarantee a reliable reception of the exchanged information between the SCPs of the considered collaborative system even if the channel conditions are not good. This technique supports transmitting simultaneously multi data-classes over wireless link where each data-class has a priority depending on its importance in microgrid operation. In this paper, we opt to use this modulation technique for the communicated contribution power (P_c) data of each microgrid has a high priority (HP) whereas the schedulability data of loads (R vector) has a low priority (LP). The stream with high priority has a big probability to be received even if the channel conditions are bad. However, the second information are well received when the channel condition allows. The reason behind considering the (P_c) as a high prior data is to keep the power balancing as well to avoid any blackout in the system. Besides, associating a LP to the R matrix will not present a danger in the safety of the grid but it will change the consumption behavior of some residences.

The hierarchical 16-QAM constellation is coded 4 bits per symbol which are distributed as shown in Fig. 3. The two low significant bit (LSB) is used for the data stream with high priority (HP) while the two most significant bits (MSB) are used for the data stream with low priority (LP)

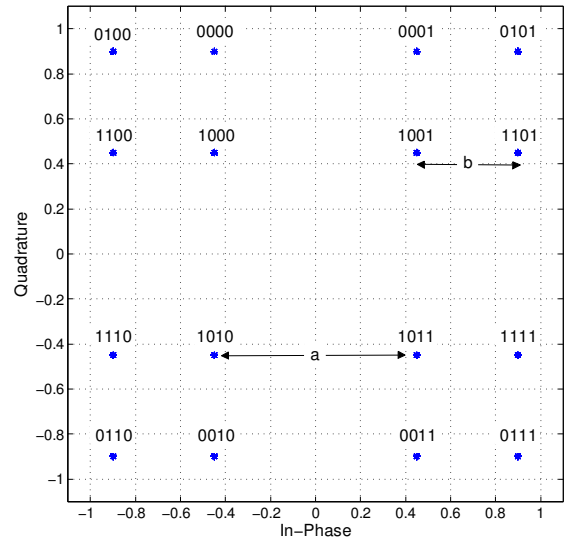


Fig. 3: Non-uniform Hierarchical 16-Quadrature Amplitude Modulation Constellations

[8]. The principle of this idea, is that the LSB (The bits on the right of each symbol) is represented in all symbols of the same quadrant and the MSB bits indicates the position inside the same quadrant. Consequently, the HP stream is more reliably transmitted and protected with low Signal-to-noise ration (SNR). Whereas, the LP stream requires a good channel condition and that means a high SNR. This property of hierarchy introduces a new behavior to conventional QAM technique allowing a continuous transmission of data even if the channel conditions are bad. Then, the HP stream can benefit from the channel bandwidth more than the LP stream in this case. Otherwise, both HP and LP benefit from the transmitting over the channel.

In order to give a robust structure to the proposed modulation, other modifications are added to this latter in the ratio constellation α which represents the ratio a/b [9]. The parameter (a) is the distance between symbols located in adjoining quadrants and the parameter b is the distance between adjacent symbols in the same quadrant as shown in Fig. 3. In the conventional M-QAM ($\alpha = 1$) and that makes the M symbols positioned within a uniform distribution, which means that the distance b is the same as the distance a . Indeed, the parameter α of the proposed hierarchical 16-QAM is increased to the value 2 so as to give a non-uniform behavior [7] to this modulation technique. Then, this modification leads to an increase in the average transmission power, but also to a decrease in the required SNR ratio for the HP stream [8]. Moreover, increasing alpha value allows an increasing in the spatial separation between the symbols located in adjacent quadrants and consequently improving the protection of HP data.

IV. SIMULATION AND RESULTS

In this section, we demonstrate the simulation results using an example to examine the performance of the proposed DARET algorithm in power management based on a non-uniform hierarchical 16-QAM. We generate, with a step size of 6 minutes, a daily data of the contribution solar and wind

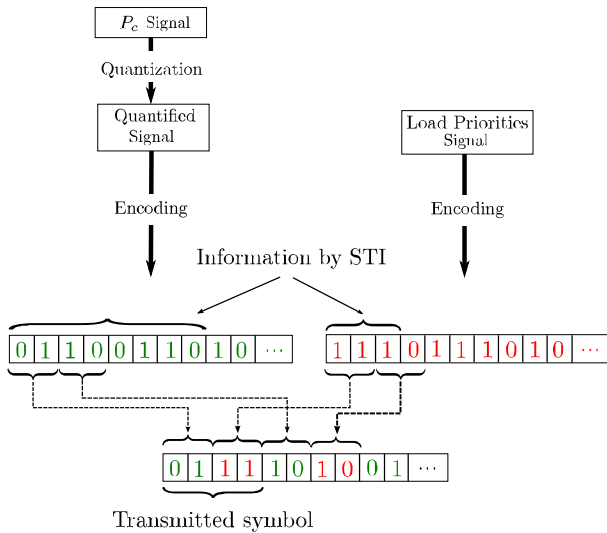


Fig. 4: Transmitted information

power and of scheduled loads vector for each microgrid. Then we have prepared the full data which is a combination of P_c and R vector data. Fig. 4 shows the procedure followed to prepare the transmitted signal. This signal is modulated with the non-uniform hierarchical 16-QAM with a constellation ratio $\alpha = 2$. Fig. 5 shows that the HP data is more protected than the LP data without much degrading the reception quality of LP data. Fig. 6 shows the received signals in terms of contribution power and priorities matrices broadcasted in the system by the individual microgrid. We note that, for $\text{SNR}=25\text{dB}$, the P_c data is received with no errors (the curves of the received and submitted data are perfectly matched) and for $\text{SNR}=15\text{dB}$ with three errors. Whereas, the R vector has some errors for $\text{SNR}=15\text{dB}$ and no errors for $\text{SNR}=25\text{dB}$.

After receiving the P_c and the R data at each SCP, the latter run the DARET algorithm in order to take decisions of switching on/off of scheduled loads. Fig. 7 shows the consumption power (●) of the whole system in terms of the received contribution power (∇) and scheduled loads vector for both cases $\text{SNR}=15\text{dB}$ (7a, 7b) and $\text{SNR}=25$ (7c, 7d). We note that, for a small number ($N = 6$) of collaborative microgrids, the disparity between the curves of consumption and of generation is important. However, for a large number of microgrids ($N = 6000$), the disparity becomes smaller. These results demonstrate the reliability of DARET algorithm specially for a collaborative system of a large number of microgrids.

We note that the running of the algorithm in each SCP allows, in one hand, to ensure the redundancy, and in the other hand, to avoid the time and the impact of broadcasting decision, unlike the system management in one centralized SCP.

V. CONCLUSION

This paper presents a dynamic assignment of renewable energy tokens (DARET) algorithm in order to add a smart collaborative behavior to a group of microgrids. The proposed scenario is an islanded microgrids model which collaborate with the power provided from their individual green energy sources. The role of DARET algorithm is to manage power sharing and to maintain, at the same time, the active power

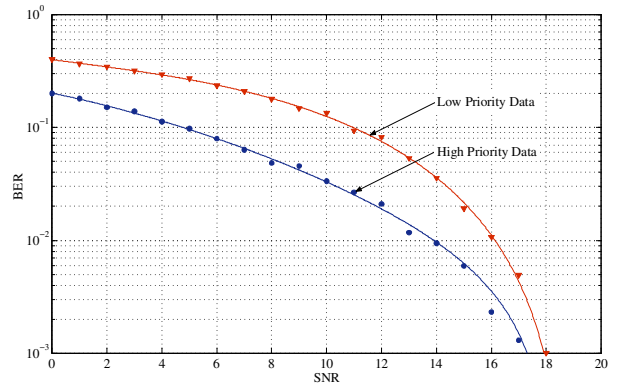
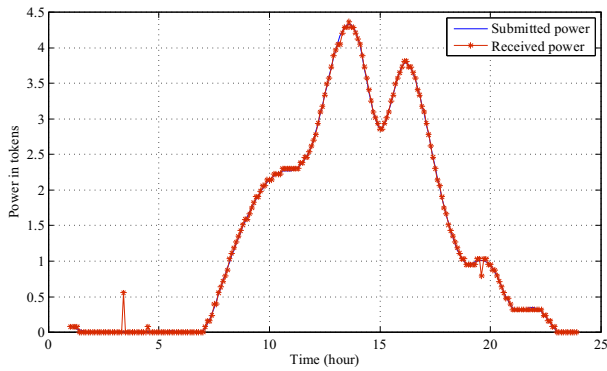


Fig. 5: BER of HP and LP data

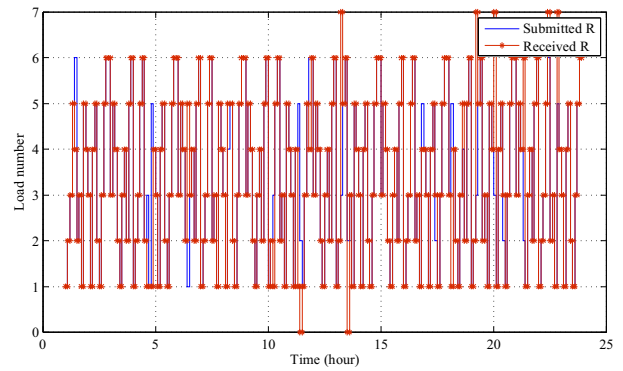
balancing in the microgrids system. For the reactive power, which has an impact on the network voltage profile, will be studied in our future work in order to reach a global power balancing. This algorithm relies on some equipments such SCPs and LCs. The SCP is installed in each microgrid and is designed to execute DARET as well as broadcasts its decisions (switch on or switch off) to the whole microgrid LCs. Indeed, the SCP makes its decisions based on the total contribution power, the instant consumption power information and the scheduled loads of each microgrid. Then, the operation of DARET algorithm is based on exchanging many information between the entities of the whole system. For this reason, a non-uniform hierarchical 16-QAM is used to provide a reliable data transmission over wireless links. At last, simulation results show in one hand, the effectiveness of the proposed algorithm, specifically, when the number of the collaborative microgrids is large which lead to negligible power losses. In the other hand, the robustness of the modulation technique in protecting broad-casted data specially the contribution power which allow to keep power balancing even if errors occurred in the transmission.

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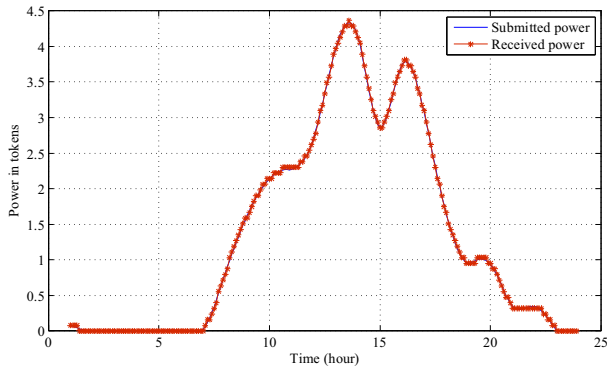
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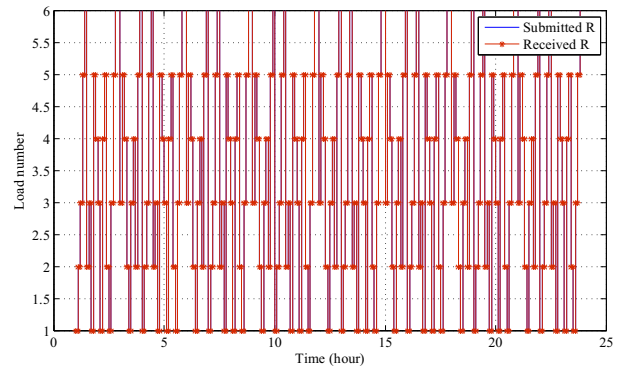
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(b)

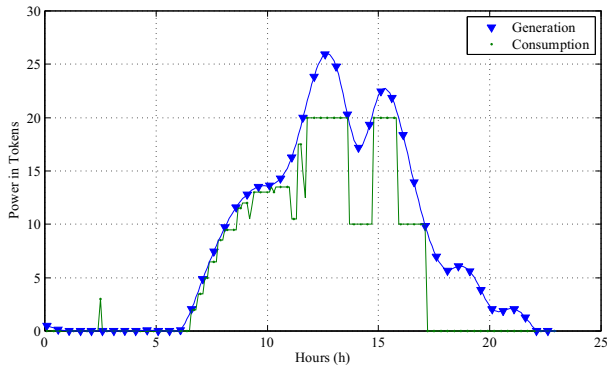


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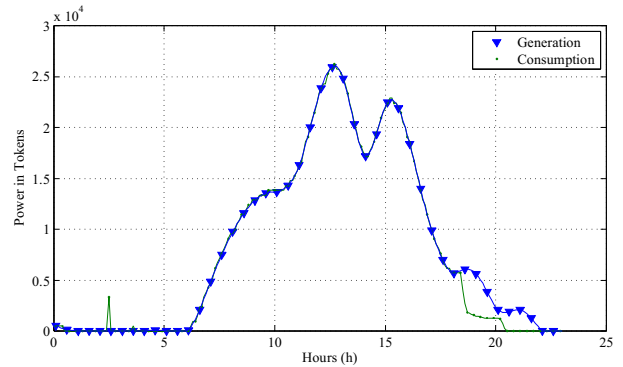


(d)

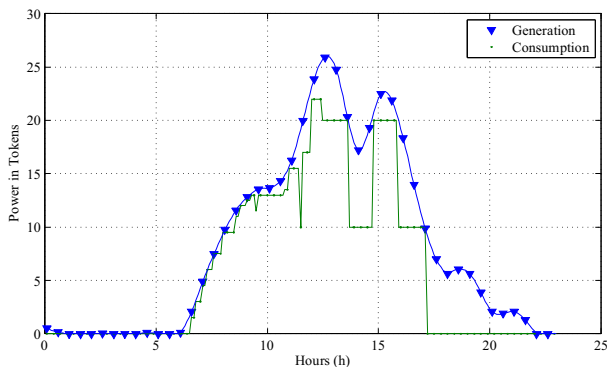
Fig. 6: Submitted and received signals of (a) P_c with SNR=15dB, (b) R vector with SNR=15dB, (c) P_c with SNR=25dB and (d) R vector with SNR=25dB.



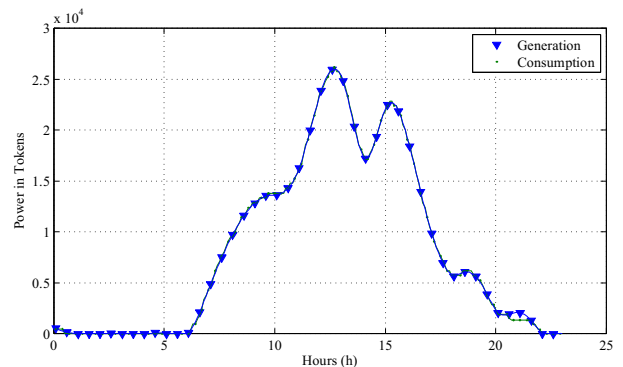
(a)



(b)



(c)



(d)

Fig. 7: Total available and consumed power during 24hours for (a) $N = 6$ microgrids and SNR= 15dB, (b) $N = 6000$ microgrids and SNR= 15dB, (c) $N = 6$ microgrids and SNR= 25dB, (d) $N = 6000$ microgrids and SNR= 25dB.