Available *online* at : http://jnte.ft.unand.ac.id/

Jurnal Nasional Teknik Elektro

| ISSN (Print) 2302-2949 | ISSN (Online) 2407-7267 |

Feasibility Analysis of Distributed Power Control System in Cognitive Radio Networks

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ARTICLE INFORMATION

Received: January 12, 2022
Revised: March 17, 2022
Available online: March 29, 2022

KEYWORDS

cognitive radio network, distributed power control, eigenvalue, feasibility, SINR

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A B S T R A C T

The need for an efficient transmit power is affected by the condition of user and power control methods used. User conditions that categorized in cognitive femtocell networks included in the category as distributed user, so it required a distributed power control (DPC). To be implemented in cognitive radio network (CRN) communication, the system must be feasible. The problem raised in this research regarding the feasibility of implementing the DPC system on the CR network To meet the feasible requirements, it is necessary to test the system's feasibility through testing the eigenvalues of the link gain matrix obtained and testing the non-negative power vector conditions. In this study, experiments were carried out on 2 schemes of the number of users, namely the scheme of 5 users and 10 users, to determine the power requirements of each user according to the channel distribution. The results obtained for both schemes show that the total eigenvalue of the link gain matrix for all channels is less than 1 and all users meet the non-negative power vector requirements. So it can be concluded that those two schemes are feasible to implement a distributed power control system. Furthermore, as more users use the channel and the closer the distance between users, the more power is consumed due to high interference, necessitating high power compensation in order to maintain the target of signal to interference and noise ratio (SINR).

INTRODUCTION

Femtocell is present as a data access network solution that can be installed by customers to increase coverage area. The development of a cognitive femtocell network (CFN) is able to provide a solution to increase cost effectiveness in several scenarios related to spectrum scarcity. This is because a femtocell network can be implemented to share spectrum with a macrocell network [1]. Although femtocells provide significant benefits for mobile operator users, their existence faces many challenges, including interference. This interference is caused by the disproportionate use of transmit power by each user. Therefore, it is necessary for an uplink power control system to be applied on the user side to control the interference between cells that is generated, so as to minimize interference that will occur [2]. This is because the purpose of power control is to ensure that the transmit power from the transmitter will be able to reach a high-enough level to be detected by the receiver and low-enough level to avoid interference to other users.

Power control systems have been widely applied to mobile networks, but most of them are still centralized [3]. While the characteristics of users are distributed, centralized power control (CPC) is no longer considered suitable for application [4]. This is because in a centralized power control system, the power control process is handled by the base station so that the user does not need to do anything, which means that the user does not have power control independently. In addition, the complexity of the centralized power control system affects the quality of the communication system. In order to reduce the complexity of the centralized system, a power control method that is really suitable for cognitive radio (CR) systems with self-organized user characteristics is needed. Several studies focus on power control systems using centralized mechanisms in multi-channel CFN implementation [5], on power control as interference management for device to device (D2D) communication [6], and aims to improve the performance of cellular communication systems and increase the spectral efficiency of cell edge users [7]. Some focus on power control systems using distributed mechanisms aimed at reducing control complexity at the base station [8]. Many algorithms are very simple to implement in distributed power control (DPC) schemes, but their convergence speed and power utilization ratio are still low, making them difficult to accommodate in a dynamic cognitive radio communication environment.

The problem raised in this research regarding the feasibility of implementing the DPC system on the CR network. With two different schemes, namely the 5 user and 10 user schemes, the goal of this research is to determine whether the DPC system is feasible for femto users. It is the focus of these two schemes to

https://doi.org/10.25077/jnte.v11n1.994.2022

demonstrate how the number of users has an impact on the system's viability. Assuming that the system passes the feasibility test or is capable of attaining a feasible condition, it is considered to be feasible to put into operation. Meanwhile, if the system does not pass the feasibility test, or in other words, if it is not feasible, it can not be implemented.

The organization of the paper consists of: Introduction which has been described in first chapter, Method is explained in second chapter, third chapter focuses on the Results and Discussion, and the last chapter shows the Conclusions.

METHOD

System Model

The system model used in this study is based on an ad-hoc network. It consists of several pairs of femto user equipments (FUEs) or often referred to as femto users as transmitters and femto access points (FAPs) as receivers for each node in the cognitive femtocell network as illustrated in Figure 1 below:

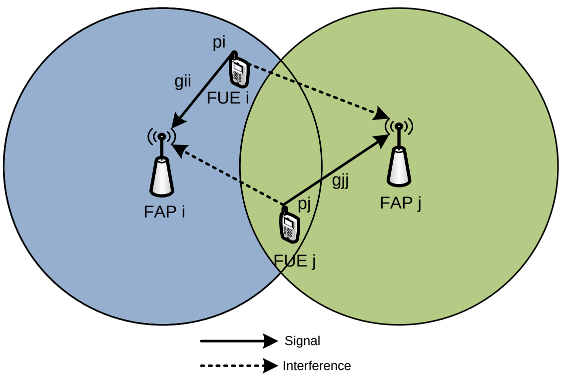

Figure 1. System model of Distributed Power Control

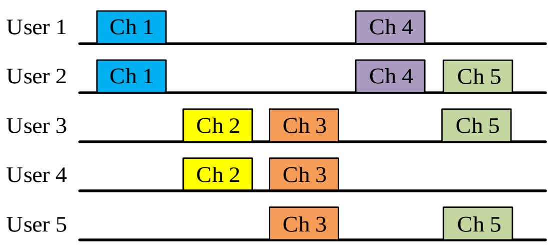

Figure 2. Channel distribution for 5 user scheme

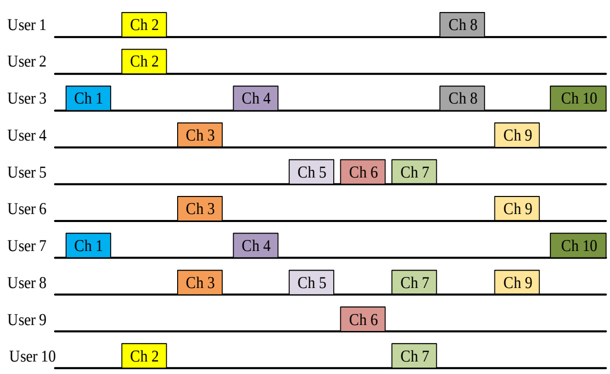

Figure 3. Channel distribution for 10 user scheme

The analysis on the DPC includes the analysis of the feasibility and convergence tests. In this study, only the analysis of the feasibility test was carried out. The feasibility test is carried out based on the absolute eigenvalue of the ***H*** matrix which must be less than 1 (|*eigenvalue* ***H***|<1) and meet the requirements of non-negative power vector. In this test, it will be proven that if the eigenvalue conditions meet these requirements, a non-negative power vector condition will be achieved, which means that the condition is feasible. Vice versa if the eigenvalue conditions are not met, then the power vector will be negative, which means that the feasible conditions for the system are not achieved (infeasible). This testing procedure can be shown in Figure 4 below.

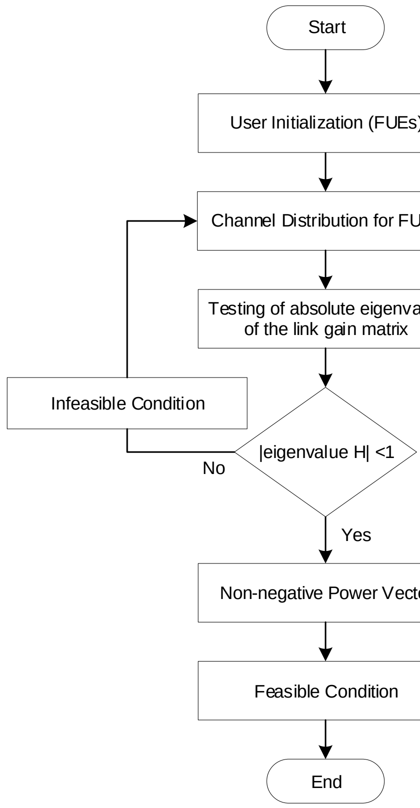

Figure 4. Flowchart of feasiblity testing

Power Vector

If given the target SINR, γ^{tar}, to get a feasible solution with N users, it is necessary to meet the requirements of a non-negative power vector, namely P^* which can be obtained as follows [9]:

$$P^* = (I - H)^{-1}\eta \tag{1}$$

where $H = (h_{ij})$ is normalized *link gain* matrix which satisfies the following equation [9]:

$$h_{ij} = \gamma^{tar}\frac{G_{ij}}{G_{ii}} \;\; for \;\; i \neq j; h_{ij} = 0 \; for \;\; i = j \tag{2}$$

where G_{ij} and G_{ii} are the link gain of user *i* to user *j* and the link gain of user *i* itself, and $\eta = (\eta_i)_{i=1...N}$ is normalized vector *noise* [9]:

$$\eta_i = \gamma^{tar}\frac{\sigma}{G_{ii}} \tag{3}$$

with σ^2 is received noise.

https://doi.org/10.25077/jnte.v11n1.994.2022

The power vector for the k-th user group can be formed based on the following equation [9]:

$$P_k^* = (I - H_k)^{-1}\eta_k \quad for\ k = 1,2,\dots,K \tag{4}$$

with $k_i = 1, 2, \dots, K$ determines the transmission channel selected by user i, i N. The notationis the power vector for the kth user group. $H_k = (h_{ij})$ is the normalized link gain matrix on the k-th channel that satisfies the following equation [9]:

$$H_k = (h_{ij})\ for\ s_i = k, s_j = k\ and\ i \neq j \tag{5}$$

with $\eta_k = (\eta_i)$ is the normalized noise vector for $s_i = k$.

Power Control

Telecommunications equipment requires power to be able to power telecommunications equipment and for the communication process, in this case transmitting power to send signals containing data or information. Telecommunication devices that require a power control system in this study can be cellular phones, laptops or other mobile communication devices.

Power control refers to setting the transmitter output power level, in the form of BTS in the downlink direction and mobile stations in the uplink direction, with the aim of increasing system capacity, user coverage and quality (data rate), and to reduce power consumption. To achieve this goal, power control mechanisms are usually aimed at maximizing the received power of the desired signal, by limiting the resulting interference.
In this study, the observed power control is in the uplink power control so that the power control process is carried out by adjusting the user transmit power so that interference can be minimized. This is because a high level of interference can limit the uplink coverage area if the power of the user who is the source of the interference is not controlled.

The classification of power control, especially in femtocells, is divided into 2 main parts, namely non-assistance-based vs assistance-based and centralized vs distributed. [10], as shown in Figure 5. However, in this case, what will be discussed further is the distributed power control (DPC).

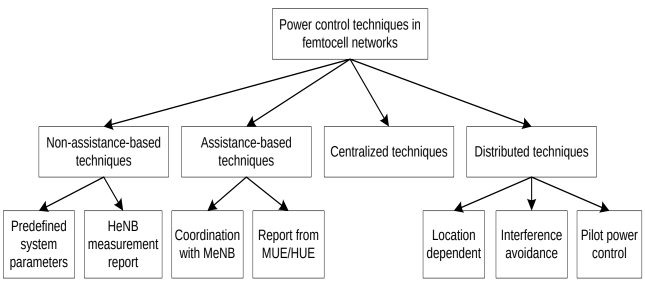

Figure 5. Classification of power control in femtocell networks

Distributed Power Control (DPC)

Distributed power control techniques avoid the bottleneck effect of centralized power control and can improve reliability by eliminating the effects of centralized failure making it advantageous to implement [10]. In DPC, an iteration process is carried out because each user functions as a controller both for himself and for other users. Power updates are carried out by each user in order to achieve convergent conditions. The determination of new power in the power update process is related to the old power used by the user. Power update on DPC is obtained based on the SINR condition of the user and the previous user's power.
To find out the power value in a distributed system, refer to the power update equation related to the previous power in the DPC approach [11]:

$$p_i^{(t+1)} = \frac{\gamma_i^{tar}}{\gamma_i^{(t)}} p_i^{(t)} \tag{6}$$

where γ_i^{tar} is target SINR and $\gamma_i^{(t)}$ is SINR achieved by user *i* at time *t*, while $p_i^{(t+1)}$ and $p_i^{(t)}$ are power user *i* before and after the iterations. This method is also known as the Power Balancing Algorithm (PBA).

Feasibility of DPC System

At the physical layer, power control can reduce interference, and for a feasible system, the results for all users must meet the specified signal to interference plus noise ratio (SINR) limits. Users can adjust transmission power levels via distributed power control to ensure that all users sharing the same channel meet the target SINR requirements of the intended receiver. For users sharing the same frequency channel, the transmission power will affect the link quality and the interference temperature on a particular channel. Therefore, the purpose of power control is to adjust the transmission power of all users in order to improve the quality of the connection so as to allow groups of users to transmit over the same channel to meet a certain BER target.

The feasibility of the DPC means that for all initial power control it is able to reach a convergent condition at a certain power value (P^*) and at the same time all users reach the target SINR at a positive power value up to the maximum power value, $0 \leq P^* \leq P_{max}$ [4]. With this feasibility test it can be seen if the negative user power value means that it is impossible to achieve the desired target SINR on the network, or in other words there is no feasible solution (infeasible condition). Feasibility can also be seen based on the user's maximum power usage, P_{max}, so that if the power on the user exceeds the value of P_{max}, this condition is referred to as a semi-feasible condition. It is called semi-feasible because even though it is included in the feasible category related to non-negative power vectors, the power used is very large and exceeds P_{max} to reach the target SINR. In some cases there are even those that still do not reach the target SINR even though the power has exceeded P_{max}.

From this discussion, it can be concluded that the limitations of the DPC given to each user can be drawn. Taking into account the interference factor due to the use of large power, the maximum power limit becomes important, namely:

$$P_{min} \leq p_k^* \leq P_{max} \tag{7}$$

with $P_{min} = 0\ W$ or a certain power value (related to the non-zero initial power factor in the power update process).

This is different from the feasible requirements for a centralized power control (CPC) system which only has non-negative power vector requirements [12], a distributed power control (DPC) system can be said to be feasible if it fulfills the following two conditions:

1) Value of P^* is a non-negative power vector merupakan *non-negative power vector* [13]–[16]**,** or

2) The absolute eigenvalue of the link gain matrix $\boldsymbol{H} < 1$ [15], [17]–[19]

Feasibility is also related to maximum user power. If these two conditions are met but the power used exceeds the maximum power it will not be feasible. To maintain the feasibility, it can be done in several ways, including Secondary User (SU) removal [20] or reduce interference by widening the distance between users. In this study, in addition to transferring users to other channels, SU removal is also performed for SUs that have the smallest SINR or those with high power, causing the highest interference and also decreasing the target SINR (so the number of feasible users is increasing).

RESULTS AND DISCUSSION

This section shows some results related to user analysis on feasible conditions and feasibility analysis on the DPC system which consists of testing the eigenvalues of the link gain matrix and non-negative power vector testing. User analysis and feasibility analysis were carried out on 2 user schemes, namely the 5 user and 10 user schemes.

User Analysis on DPC System

The users in Distributed Power Control (DPC) model are femto users in a homogeneous femtocell network topology that uses multi-channel.

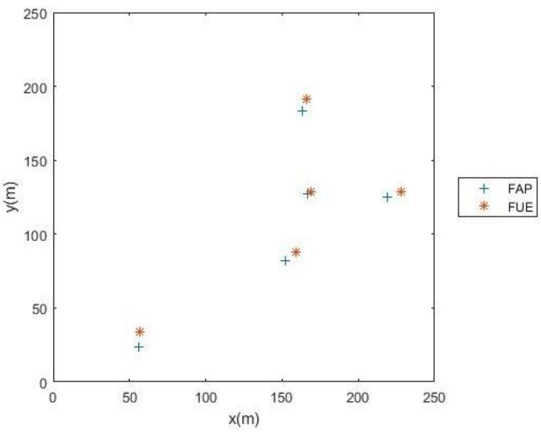

Figure 6. Femtocell network topology for 5 user scheme

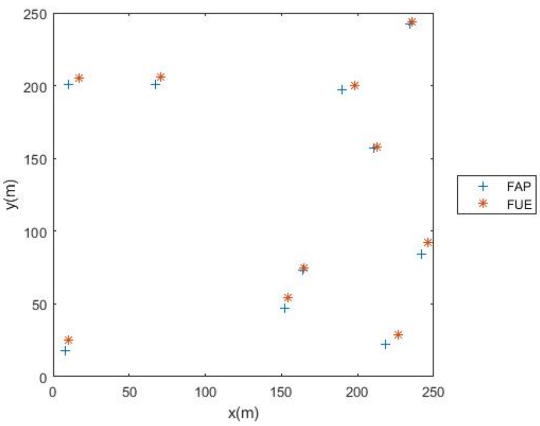

Figure 7. Femtocell network topology for 10 user scheme

Figures 6 and 7 are femtocell network topology with a scheme of 5 users and 10 users. In this topology, the user has each pair of user femto which are randomly distributed. Each pair of femto users has a different distance. The use of two schemes for the number of users as shown in Figures 6 and 7 is intended to determine the effect of increasing the number of users on a system that uses shared channels. In this study, the scheme of 5 users and 10 users was used.

Feasibility Analysis on DPC System

As previously mentioned, DPC system is said to be feasible if it fulfills the following two conditions:

1. The eigenvalue of the link gain matrix $\boldsymbol{H} < 1$, or
2. The value P* is *non-negative power vector*

then based on the network topology on the two user's schemes (5 user and 10 user schemes) the feasibility can be analyzed through the two tests.

For a feasible system, in addition to reducing interference, power control is also intended so that the SINR for all users can meet the specified SINR. For users who use the same frequency channel, the transmission power will affect the quality of the links on that channel. The user's transmission power level can be adjusted so that each user does not use excessive power, which causes a lot of battery consumption on the user's device. Power level adjustment via power control is intended to ensure that all users sharing the same channel are able to meet the target SINR requirements.

Generally, when compared to the CPC method, the feasibility analysis on the DPC system (once it converges) produces a lower power value than when using the CPC method. In addition, because it requires global information, CPC has a high level of complexity and computation [21].

Feasibility Test for 5 User Scheme

Based on Figure 2, then the $\boldsymbol{H}$ matrix can be divided into 5 types according to the number of channels. The $\boldsymbol{H_1}$ matrix is the channel-1 matrix used by two users, user 1 and user 2, so the size of the $\boldsymbol{H_1}$ matrix is 2x2, this is because it corresponds to the number of users who use the channel. Users who use channel 1 are the same as users who use channel 4, so the $\boldsymbol{H_1}$ matrix has the same value as the $\boldsymbol{H_4}$ matrix. To meet the feasible conditions, the value of |*eigenvalue* $\boldsymbol{H}$|<1. The link gain matrix value $\boldsymbol{H}$ for each shared channel use in the 5 user scheme according to Figure 2 and equation (2) is as follows:

$$\boldsymbol{H_1} = \boldsymbol{H_4} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} = \begin{bmatrix} 0 & 0.06405124 \\ 1.07255520 & 0 \end{bmatrix}$$

$$\boldsymbol{H_2} = \begin{bmatrix} h_{33} & h_{34} \\ h_{43} & h_{44} \end{bmatrix} = \begin{bmatrix} 0 & 0.20376831 \\ 0.27167063 & 0 \end{bmatrix}$$

$$\boldsymbol{H_3} = \begin{bmatrix} h_{33} & h_{34} & h_{35} \\ h_{43} & h_{44} & h_{45} \\ h_{53} & h_{54} & h_{55} \end{bmatrix} = \begin{bmatrix} 0 & 0.20376831 & 0.03651004 \\ 0.27167063 & 0 & 0.04777266 \\ 0.06041211 & 0.05850832 & 0 \end{bmatrix}$$

$$\boldsymbol{H_5} = \begin{bmatrix} h_{22} & h_{23} & h_{25} \\ h_{32} & h_{33} & h_{35} \\ h_{52} & h_{53} & h_{55} \end{bmatrix} = \begin{bmatrix} 0 & 0.18803229 & 0.11560693 \\ 0.12089094 & 0 & 0.03651004 \\ 0.17830346 & 0.06041211 & 0 \end{bmatrix}$$

- Eigenvalue Testing for 5 User Scheme

The eigenvalues of the link gain matrix $\boldsymbol{H}$ in the 5 user scheme are as follows:

$$eigH_1 = eigH_4 = \begin{bmatrix} -0.26210397 \\ 0.26210397 \end{bmatrix}$$

https://doi.org/10.25077/jnte.v11n1.994.2022

$$eigH_2 = \begin{bmatrix} -0.23528252 \\ 0.23528252 \end{bmatrix}$$

$$eigH_3 = \begin{bmatrix} 0.25484014 \\ -0.23535983 \\ -0.01948030 \end{bmatrix}$$

$$eigH_5 = \begin{bmatrix} 0.23773750 \\ -0.18084639 \\ -0.05689110 \end{bmatrix}$$

Based on these results, the |eigenvalue ***H***|<1 is met in all link gain matrix values $\boldsymbol{H_1}$ to $\boldsymbol{H_5}$, such as:

$$|eigH_1| = |eigH_4| = \begin{bmatrix} 0.26210397 \\ 0.26210397 \end{bmatrix} < 1$$

$$|eigH_2| = \begin{bmatrix} 0.23528252 \\ 0.23528252 \end{bmatrix} < 1$$

$$|eigH_3| = \begin{bmatrix} 0.25484014 \\ 0.23535983 \\ 0.01948030 \end{bmatrix} < 1$$

$$|eigH_5| = \begin{bmatrix} 0.23773750 \\ 0.18084639 \\ 0.05689110 \end{bmatrix} < 1$$

These results show a feasible condition for all users. This is because the absolute value of the eigenvalue matrix ***H*** for all users on all channels is less than one or (|eigenvalue ***H***|<1), so that it fulfills the feasible conditions.

- Non-Negative Power Vector Testing for 5 User Scheme

By using equation (4), the power vector value P* of each user according to the channel distribution for the 5 user scheme is as follows:

$$P_1{}^* = P_4{}^* = \begin{bmatrix} 0.0913018708433828 \\ 0.635513499032253 \end{bmatrix} mW$$

$$P_2{}^* = \begin{bmatrix} 0.621082510279128 \\ 0.782211745633163 \end{bmatrix} mW$$

$$P_3{}^* = \begin{bmatrix} 0.65666338722083 \\ 0.826599839563402 \\ 0.726813487552514 \end{bmatrix} mW$$

$$P_5{}^* = \begin{bmatrix} 0.739904944021178 \\ 0.580559429394863 \\ 0.805780530519359 \end{bmatrix} mW$$

Based on the conditions of the eigenvalues of the ***H*** matrix that meet the feasible requirements, namely the |eigenvalue ***H***| which is smaller than 1, then automatically the power vector values generated are all positive (non-negative power vectors), which means that the system is feasible. The power required by each of 5 users and its allocation to each channel is shown in Table 1 below:

Table 1. Power alocation for 5 user scheme

User	Channel	Power Required (mW)
1	1	0.0913018708433828
	4	0.0913018708433828
2	1	0.635513499032253
	4	0.635513499032253
	5	0.739904944021178
3	2	0.621082510279128
	3	0.65666338722083
	5	0.580559429394863
4	2	0.782211745633163
	3	0.826599839563402
5	3	0.726813487552514
	5	0.805780530519359

Feasibility Test for 10 User Scheme

Meanwhile, based on the number of channels and users in Figure 3, which is a 10 user scheme, the link gain matrix ***H*** can be divided into 10 types as follows:

$$\boldsymbol{H_1} = \boldsymbol{H_4} = \boldsymbol{H_{10}} = \begin{bmatrix} h_{33} & h_{37} \\ h_{73} & h_{77} \end{bmatrix} = \begin{bmatrix} 0 & 0.01498731 \\ 0.00112779 & 0 \end{bmatrix}$$

$$\boldsymbol{H_2} = \begin{bmatrix} h_{11} & h_{12} & h_{110} \\ h_{21} & h_{22} & h_{210} \\ h_{101} & h_{102} & h_{1010} \end{bmatrix} = \begin{bmatrix} 0 & 0.0703125 & 0.19667170 \\ 0.00242967 & 0 & 0.00280513 \\ 0.09316406 & 0.03442055 & 0 \end{bmatrix}$$

$$\boldsymbol{H_3} = \boldsymbol{H_9} = \begin{bmatrix} h_{44} & h_{46} & h_{48} \\ h_{64} & h_{66} & h_{68} \\ h_{84} & h_{86} & h_{88} \end{bmatrix} = \begin{bmatrix} 0 & 0.01664739 & 0.00069862 \\ 0.21470588 & 0 & 0.00949092 \\ 0.00490412 & 0.00769553 & 0 \end{bmatrix}$$

$$\boldsymbol{H_5} = \begin{bmatrix} h_{55} & h_{58} \\ h_{85} & h_{88} \end{bmatrix} = \begin{bmatrix} 0 & 0.01159047 \\ 0.00832388 & 0 \end{bmatrix}$$

$$\boldsymbol{H_6} = \begin{bmatrix} h_{55} & h_{59} \\ h_{95} & h_{99} \end{bmatrix} = \begin{bmatrix} 0 & 0.01639269 \\ 0.00836260 & 0 \end{bmatrix}$$

$$\boldsymbol{H_7} = \begin{bmatrix} h_{55} & h_{58} & h_{510} \\ h_{85} & h_{88} & h_{810} \\ h_{105} & h_{108} & h_{1010} \end{bmatrix} = \begin{bmatrix} 0 & 0.01159047 & 0.06629223 \\ 0.00832388 & 0 & 0.02310151 \\ 0.05518278 & 0.02109499 & 0 \end{bmatrix}$$

$$\boldsymbol{H_8} = \begin{bmatrix} h_{11} & h_{13} \\ h_{31} & h_{33} \end{bmatrix} = \begin{bmatrix} 0 & 0.01525960 \\ 0.00791717 & 0 \end{bmatrix}$$

- Eigenvalue Testing for 10 User Scheme

The eigenvalues of the link gain matrix ***H*** for the 10 user scheme are as follows:

$$eigH_1 = eigH_4 = eigH_{10} = \begin{bmatrix} -0.00411127 \\ 0.00411127 \end{bmatrix}$$

$$eigH_2 = \begin{bmatrix} 0.14947112 \\ -0.13288811 \\ -0.01658301 \end{bmatrix}$$

$$eigH_3 = eigH_9 = \begin{bmatrix} 0.06068400 \\ -0.06015553 \\ -0.00052846 \end{bmatrix}$$

$$eigH_5 = \begin{bmatrix} -0.00982230 \\ 0.00982230 \end{bmatrix}$$

$$eigH_6 = \begin{bmatrix} -0.01170835 \\ 0.01170835 \end{bmatrix}$$

$$eigH_7 = \begin{bmatrix} 0.06804560 \\ -0.06175979 \\ -0.00628580 \end{bmatrix}$$

$$eigH_8 = \begin{bmatrix} -0.01099149 \\ 0.01099149 \end{bmatrix}$$

Based on these results, the |eigenvalue ***H***|<1 is met in all link gain matrix values $\boldsymbol{H_1}$ to $\boldsymbol{H_{10}}$, such as:

$$|eigH_1| = |eigH_4| = |eigH_{10}| = \begin{bmatrix} 0.00411127 \\ 0.00411127 \end{bmatrix}$$

$$|eigH_2| = \begin{bmatrix} 0.14947112 \\ 0.13288811 \\ 0.01658301 \end{bmatrix}$$

$$|eigH_3| = |eigH_9| = \begin{bmatrix} 0.06068400 \\ 0.06015553 \\ 0.00052846 \end{bmatrix}$$

$$|eigH_5| = \begin{bmatrix} 0.00982230 \\ 0.00982230 \end{bmatrix}$$

$$|eigH_6| = \begin{bmatrix} 0.01170835 \\ 0.01170835 \end{bmatrix}$$

$$|eigH_7| = \begin{bmatrix} 0.06804560 \\ 0.06175979 \\ 0.00628580 \end{bmatrix}$$

$$|eigH_8| = \begin{bmatrix} 0.01099149 \\ 0.01099149 \end{bmatrix}$$

These results show a feasible condition for all users. This is because the absolute value of the eigenvalue of the ***H*** matrix for all channels is less than one or (|eigenvalue ***H***|<1), so that it meets the feasible conditions.

- Non-Negative Power Vector Testing for 10 User Scheme

By using equation (4), the value of the power vector P* according to the channel division in the 10 user scheme is as follows:

$$P_1{}^* = P_4{}^* = P_{10}{}^* = \begin{bmatrix} 0.185209646918386 \\ 0.0144391272961588 \end{bmatrix} mW$$

$$P_2{}^* = \begin{bmatrix} 0.408348976874681 \\ 0.0157537713003339 \\ 0.189426347486703 \end{bmatrix} mW$$

$$P_3{}^* = P_9{}^* = \begin{bmatrix} 0.0264523797115769 \\ 0.214889667774234 \\ 0.152624061059172 \end{bmatrix} mW$$

$$P_5{}^* = \begin{bmatrix} 0.229454442739814 \\ 0.152750595863496 \end{bmatrix} mW$$

$$P_6{}^* = \begin{bmatrix} 0.229628301956172 \\ 0.118608336729263 \end{bmatrix} mW$$

$$P_7{}^* = \begin{bmatrix} 0.240599218682179 \\ 0.156711097156262 \\ 0.167423399149797 \end{bmatrix} mW$$

$$P_8{}^* = \begin{bmatrix} 0.372854456454113 \\ 0.187945196794578 \end{bmatrix} mW$$

Based on the conditions of the eigenvalues of the ***H*** matrix that meet the feasible requirements, namely the |eigenvalue ***H***| which is smaller than 1, then automatically the power vector values generated are all positive (non-negative power vectors), which means that the system is feasible. The power required by each of 10 users and its allocation to each channel is shown in Table 2.

It can be seen from Table 2 and Figure 3 that users who use multiple channels tend to have more power than users who only use one channel. This is because the more channels used, the more interference there will be, and in order to compensate for the increased interference, more power will be required to keep the SINR on target. Furthermore, the distance between users has an impact on user power. The closer the distance, the greater the interference, and the higher the power consumed.

Table 2. Power alocation for 10 user scheme

User	Channel	Power Required (mW)
1	2	0.408348976874681
	8	0.372854456454113
2	2	0.0157537713003339
3	1	0.185209646918386
	4	0.185209646918386
	8	0.187945196794578
	10	0.185209646918386
4	3	0.0264523797115769
	9	0.0264523797115769
5	5	0.229454442739814
	6	0.229628301956172
	7	0.240599218682179
6	3	0.214889667774234
	9	0.214889667774234
7	1	0.0144391272961588
	4	0.0144391272961588
	10	0.0144391272961588
8	3	0.152624061059172
	5	0.229454442739814
	7	0.156711097156262
	9	0.152624061059172
9	6	0.118608336729263
10	2	0.189426347486703
	7	0.167423399149797

CONCLUSIONS

Based on the feasibility test results of the distributed power control system, it can be concluded that if the absolute value of the eigenvalue of the link gain matrix meets the standard, which is less than 1 (|eigenvalue H|<1), it produces a non-negative power vector value, which means that the system is feasible and can be implemented. This applies to both schemes, namely the 5 user and 10 user schemes. Furthermore, as more users use the channel and the closer the distance between users, the more power is consumed due to high interference, necessitating high power compensation in order to maintain the target SINR. The next research is related to the analysis of the convergence of the distributed power control system.

ACKNOWLEDGMENT

This research was funded by LPPM Institut Teknologi Telkom Purwokerto in the form of an internal grant 2021.

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NOMENCLATURE

γ_i^{tar}	target SINR
$\gamma_i^{(t)}$	SINR achieved by user *i*
P^*	non-negative power vector
H	normalized *link gain* matrix
G_{ij}	link gain of user *i* to user *j*
G_{ii}	link gain of user *i* itself
η	normalized vector *noise*
$p_i^{(t)}$	power user *i*
P_{max}	user's maximum power usage
P_{min}	user's minimum power usage
$eigH$	eigenvalues of the link gain matrix $\boldsymbol{H}$

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