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Performance Analysis of Game Theoretical Approach for Power Control System in Heterogeneous Network

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Abstract: The development of wireless technology, especially small cell communication systems, is now very flexible to be developed. As a form of network densification to improve the performance of the macrocell network, the combination with smallcell, in this case the femtocell network, forms a heterogeneous networks (Hetnets). However, with many networks running concurrently, a combination network between macrocell and smallcell networks, interference is unavoidable. To overcome this problem, it can be solved by applying the power control technique independently by the user. One of the independent power control methods is using a game theory approach. The use of game theory in power control or Game-Theoretical Power Control is often also referred to as Power Control Game (PCG). By determining the appropriate utility function, optimal power is obtained each time using the power update iteration process. The study addresses the issue of achieving the target SINR for both femto and macro users on heterogeneous networks by proposing a PCG that is capable of exceeding the target SINR upon convergence, implying improved communication quality. Based on the results of the feasibility and convergence tests, the proposed system has been proven to meet the requirements for existence and uniqueness, which are the requirements for meeting the feasibility and convergence of the system. The results of the performance comparison also show that when reaching convergence, both femtocell and macrocell users using the Proposed PCG method are able to exceed the specified target of signal to interference and noise ratio (SINR) in each network type. Meanwhile, using the Koskie Gajic (KG) and Al Gumaei (AG) methods, both femtocell and macrocell users could not reach the target SINR. So it can be concluded that in terms of achieving the target SINR, the Proposed PCG method is better than the other two methods.

Keywords: Power control game, Heterogeneous network, Utility function, Power update, SINR.

1. Introduction

A fifth generation (5G) communication requires a high demand for data rates. To overcome the data rate requirement is to enable network densification using small cells. Densification results in higher spectral efficiency and also reduces user power consumption. This solution significantly increases network coverage. Small cells such as low power femtocells typically used indoors or higher power picocells, used to increase macrocell coverage outdoors. Simultaneous operation between macrocell, microcell, picocell and femtocell is referred to as heterogeneous networks (HetNets) [1].

The implementation of HetNets will definitely cause additional interference, especially for users at the edge cells of macrocells and small cells that use the same channel. HetNet's performance in overcoming user interference is very important to improve. Therefore, effective interference management is needed to reduce interference [2]. This interference is caused by the disproportionate use of transmit power by each user. Therefore, it is necessary to have an uplink power control system that is applied on the user side to control the interference between cells that is generated, so as to minimize the interference that occurs [3].

Game theory methods for power control have been widely implemented in wireless cellular networks [4, 5]. Not only for power control implementation, game theory is also applied to combine power distribution and data rate for cognitive radio network [6], to manage interference

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on two-tier networks [7], or on decision making to improve network optimization performance [8], and can offer higher SINR rates [9], in both cooperative game theory [10] and non-cooperative game theory [11].

The PCG method is a power control system based on a game theory approach by proposing certain utility functions. The SINR target is accommodated in the utility function to get the required power so that it can achieve the desired SINR target. The results of the application of utility functions using a game theoretical approach tend to exceed the target SINR, while the Distributed Power Control (DPC) method that using Power Balancing Algorithm (PBA) is only able to achieve the SINR target without exceeding it [12, 13]. Utility functions can also be formulated for increased network throughput and capacity based on power limits and total interference [14]. Research on power control games for femtocell networks has also been carried out by several previous studies, such as research [15] shows that the more users in a homogeneous femtocell network the smaller the power used by the user and the fewer iterations to achieve convergence. While [16] studied about power control games on the Cognitive Radio Network (CRN) and [12] researching the implementation of power control games on a homogeneous cognitive femtocell network (CFN).

The development of small cell technology, especially the implementation of femtocells, makes the importance of heterogeneous networks to overcome interference between macro users and femto users. Previous research related to the implementation of PCG on a heterogeneous network was compared to the DPC method (PBA) and concluded that Proposed PCG is better than DPC method (PBA) [13]. There has been previous research into power control using game theory, but it has not been successful in exceeding the predetermined target SINR under convergent conditions, and even if it does reach the maximum, it can only produce the same SINR as the target [17, 18], especially if the β value is small, it will result in a SINR that is significantly lower than the target SINR, as there is a reduction of approximately 12.7% [18]. By failing to achieve the desired SINR, the communication quality is compromised. The study addresses the issue of achieving the target SINR for both femto and macro users on heterogeneous networks by proposing a PCG that is capable of exceeding the target SINR upon convergence, implying improved communication quality.

Based on this background, this study will compare the performance of the Proposed PCG method with the previous PCG method, namely the Koskie Gajic (KG) method [17] and the Al-Gumaei (AG) method [18] on heterogeneous networks. As a result of these improvements, the proposed PCG should be able to overcome the issues that have plagued previous studies, including being able to exceed the target SINR that was set right at the time of convergence.

The organization of the paper consists of: Background which has been described in Chapter 1, Research Method is explained in Chapter 2, and Chapter 3 describes the Power Control Game for Heterogeneous Network. Chapter 4 focuses on the Results and Discussion, and Conclusions are discussed in Chapter 5.

2. Research method

2.1 System model

In this study, heterogeneous networks were focused on macrocell and femtocell networks. Fig. 1 shows a proposed model system of femtocell cognitive power control in a heterogeneous network (cross-tiered network) focused on: 1) a communication system between the secondary user (SU) which in this case is the femto user equipment (FUE) as the secondary user transmitter (SU-TX) with the femto access point (FAP) as the secondary user receiver (SU-RX), and 2) communication system between macro user equipment (MUE) as primary user transmitter (PU-TX) and macro base station (MBS) as primary user receiver (SU-RX). These two communication systems will interfere with each other when using the same channel.

The use of channels at the same time causes interference. This research was conducted by applying a multi-user multi-channel scheme, as shown in the channel usage scheme shown in Fig. 2.

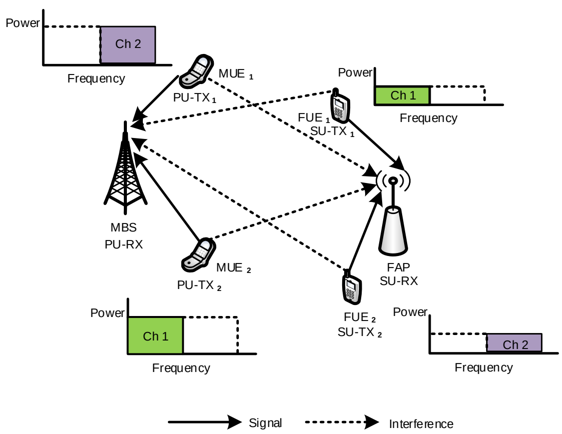

Figure. 1 Proposed system model of heterogeneous network

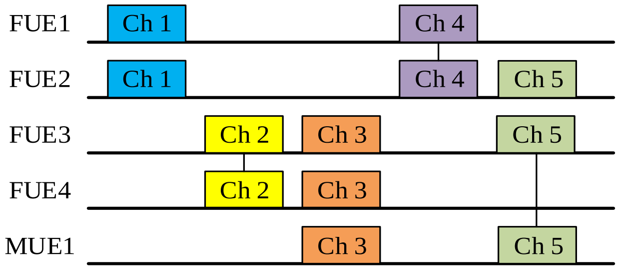

Figure. 2 Channel usage scheme [13]

The channel usage scheme will affect the SINR value obtained by the user, with the SINR equation user i (γ_i) generally as follows [19]:

$$\gamma_i = \frac{p_i g_{ii}}{\sum_{i=1, i\neq j}^{N} p_j g_{ij} + \sigma^2} \tag{1}$$

The link gain between the user transmitter i (Tx) and the user receiver i (Rx) is denoted by g_{ii}. The gain of the j th user on the link between the user Tx j and the user Rx i is denoted by g_{ij}. Let p_i is the transmission power of user transmitter i and p_j is the power of other users, and σ^2 is average of noise level that same for all receivers. The equation for calculating link gain based on user distance is as follows [20]:

$$g_{ii} = \frac{A}{d^{\alpha}} \tag{2}$$

where A is a constant equal to $A = 10^{-8}$ while α is the path loss constant of $\alpha = 4$ and d is the user distance (in meters).

Based on Eq. (1) of SINR user, the equation for SINR user macro and user femto is written as follows:

- SINR user macro:

$$\gamma_{MUE-i} = \frac{p_{i,j}\, g_{i,j}}{\sum_{\substack{j=1\\ j\neq f}}^{F} \sum_{\substack{i=1\\ i\neq m}}^{M} p_{m,f} g_{m,f} \delta_{k_{i,j}^{(x)} k_{m,f}^{(y)}} + \sigma^2} \tag{3}$$

- SINR user femto:

$$\gamma_{FUE-i} = \frac{p_{j,i}\, g_{j,i}}{\sum_{\substack{i=1\\ i\neq m}}^{M} \sum_{\substack{j=1\\ j\neq f}}^{F} p_{f,m} g_{f,m} \delta_{k_{j,i}^{(x)} k_{f,m}^{(y)}} + \sigma^2} \tag{4}$$

Notation $\delta_{k_{i,j}^{(x)} k_{m,f}^{(y)}}$ and $\delta_{k_{j,i}^{(x)} k_{f,m}^{(y)}}$ used to indicate whether or not all the user uses the same channel and k is the number of channels available. For channel usage by macro user, value $\delta_{k_{i,j}^{(x)} k_{m,f}^{(y)}} = 1$ if the value $k_{i,j}^{(x)} = k_{m,f}^{(y)}$, and if $k_{i,j}^{(x)} \neq k_{m,f}^{(y)}$ then $\delta_{k_{i,j}^{(x)} k_{m,f}^{(y)}} = 0$. Likewise for channel usage by femto users, value $\delta_{k_{j,i}^{(x)} k_{f,m}^{(y)}} = 1$ if the value $k_{j,i}^{(x)} = k_{f,m}^{(y)}$ and if $k_{j,i}^{(x)} \neq k_{f,m}^{(y)}$ then $\delta_{k_{j,i}^{(x)} k_{f,m}^{(y)}} = 0$.

2.2 Feasibility and convergence analysis

2.2.1. Feasibility testing analysis

The analysis of 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 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 are not achieved.

2.2.2. Convergence testing analysis

The analysis of the convergence test is related to the iteration process independently by the user to update the transmit power using the power update equation. Convergence testing is based on Yates proposed method [21] which includes testing positivity, monotonicity and scalability. The power value which must be non negative power vector in the feasibility test can be used to fulfill the positivity requirements in the convergence test, so that if the feasible condition is reached, the positivity requirement will be fulfilled. This shows that there is a relationship between the feasibility test and convergence.

The convergence test is related to the achievement of the Nash Equilibrium (NE) condition and is divided into 2, namely those relating to proof of NE Existence and Uniqueness.

2.2.3. Proof of NE existence

The need for the existence of Nash Equilibrium (NE) in Proposed PCG will be fulfilled by the following conditions:

a. Strategy distance {p} is limited, closed, non-empty convex set for Euclidean distance R.
b. The utility function $U_i(p)$ is continuous and quasi convex with respect to p, and fullfil this equation:

$$\frac{d^2 U_i}{d{p_i}^2} > 0 \tag{5}$$

2.2.4. Proof of NE uniqueness

The uniqueness of an NE can be determined based on the power update equation in the game's

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power control system. This section will provide evidence related to the uniqueness of an NE that converges on a unique fixed point if it meets the following conditions:

1. *Positivity*:

$$f(p_i) > 0 \quad (6)$$

2. *Monotonicity*:

$$p_1 > p_2 \rightarrow f(p_1) > f(p_2) \leftrightarrow f(p_1) - f(p_2) > 0 \quad (7)$$

3. *Scalability*:

$$\alpha f(p_i) > f(\alpha p_i), \forall \alpha > 1 \leftrightarrow \alpha f(p_i) - f(\alpha p_i) > 0 \quad (8)$$

3. Power control game for heterogeneous network

3.1 Heterogeneous networks (hetnets)

The concept of a heterogeneous network includes the use of small cells, long term evolution (LTE), WiFi coexistence, and device to device (D2D) communication [1]. The heterogeneity of the cellular wireless network is enhanced by overlaying small cells using licensed or unlicensed bands over the macrocell coverage area. While macro cells provide coverage, small cells take advantage of efficient spectrum reuse to increase network capacity and coverage. This reduces the propagation distance between the base station and the mobile user over the radio channel, thereby saving the user's power [22].

Fig. 3 shows a heterogeneous network consisting of macrocells and smallcells (picocells and femtocells). Macrocell coverage spans several kilometers and requires higher power than smallcells. Users on smallcell besides getting signals from smallcell access point (AP) also get signals from macrocell base station (BS) [1, 23].

Heterogeneous networks (HetNets) promise higher data rates, longer battery life and better cell edge performance for all mobile subscribers. In addition, HetNets are expected to play an important role in 5G networks, and its integration with Wireless Fidelity (Wi-Fi) technology will enable better data handling capacity for future mobile networks [22].

3.2 Game-theoretical power control

The application of game theory to the power control system is known as Game-Theoretical Power Control or for short, Power Control Game (PCG). PCG is a power control based on a game theory function. By determining the utility function that

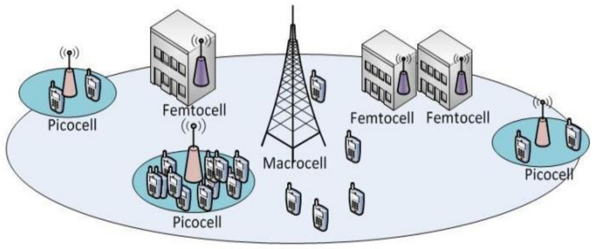

Figure. 3 Heterogeneous networks [23]

accommodates the target SINR, the iteration process can be derived from the utility function equation. The target SINR which is accommodated in the utility function is intended so that the power value obtained is able to reach the predetermined target SINR [24].

The utility function of a PCG is determined based on factors that affect system performance, such as target SINR, user SINR to be achieved, maximum user power allowed, user power, and other parameters that affect the quality of service (QoS). The power update equation on PCG is obtained from the utility function equation that has been determined previously according to the proposed model of a study. From the utility function equation, the derivative process of the power function is then carried out so that the power value is obtained for the iteration process [24]. The following is the utility function and power update from previous research, namely the Koskie Gajic (KG) method [17] and is also used in femtocell networks [25]:

$$U_i = m_i p_i + n_i(\gamma^{tar} - \gamma_i)^2 \quad (9)$$

$$p_i^{(t+1)} = \gamma_i^{tar}\left(\frac{p_i^{(t)}}{\gamma_i^{(t)}}\right) - \frac{m_i}{2n_i}\left(\frac{p_i^{(t)}}{\gamma_i^{(t)}}\right)^2 \quad (10)$$

with p_i and γ_i are power user-i and SINR user-i, $m_i/n_i = 1/48$ and the target SINR is 5 dB for FUE and 10 dB for MUE.

While the utility and power update functions from other studies, namely the Al-Gumaei (AG) method [18]:

$$U_i = \alpha_i ln\left(\frac{\gamma_i}{\gamma^{tar}} - 1\right) + c_i\left(\frac{h_i}{I_i(p_{-i})}\right)^2 \quad (11)$$

$$p_i^{(t+1)} = \gamma_i^{tar}\left(\frac{p_i^{(t)}}{\gamma_i^{(t)}}\right) - \alpha_i\left(\frac{p_i^{(t)}}{\gamma_i^{(t)}}\right)^\beta \quad (12)$$

with pricing factor α_i=5, the target SINR is 5 dB for FUE and 10 dB for MUE, and initial power is 2.22×10^{-16} W. Value of β varies i.e {1.1; 1.2; 1.3}.
In this study, we propose a utility function equation for both user femto and for user macros, and is referred to as Proposed PCG:

$$U_i = a_i {p_i}^2 - 2b_i \lambda_k \gamma_i + c_i(\gamma^{tar} - \gamma_i)^2 \quad (13)$$

$$p_i^{(t+1)} = ({\gamma_i}^{tar} + \lambda_k)\frac{p_i^{(t)}}{\gamma_i^{(t)}} - \frac{a_i\left(p_i^{(t)}\right)^3}{c_i\left(\gamma_i^{(t)}\right)^2} \quad (14)$$

with $a_i = 1$, $b_i = c_i = 4$ and channel sharing factor value λ_k is 0.5 while the target SINR is 5 dB for FUE and 10 dB for MUE.

4. Result and discussion

4.1 Analysis of feasibility and convergence

Based on the feasibility analysis, this system is feasible because it has been proven to meet the conditions of NE existence:

a. This condition is proven by being limited and closed because it is still in the range $(0, P_{max})$.
b. Continuous characteristics can be proven by observing the strategy used (power strategy) is still in the range $(0, P_{max})$, while the quasi convex is proved by the Eq. (5):

The value of the second derivative of the equation:

$$\frac{d^2U_i}{d{p_i}^2} = \frac{d\left(a_i{p_i}^2 - 2b_i\lambda_k\gamma_i + c_i\left(\gamma^{tar} - \gamma_i\right)^2\right)}{d{p_i}^2} \quad (15)$$

$$\frac{d^2U_i}{d{p_i}^2} = \frac{d\left(2a_ip_i - 2b_i\lambda_k\left(\frac{d\gamma_i}{dp_i}\right) + 2c_i(\gamma^{tar} - \gamma_i)\left(-\frac{d\gamma_i}{dp_i}\right)\right)}{dp_i} \quad (16)$$

$$\frac{d^2U_i}{d{p_i}^2} = 2a_i + 2c_i\left(\frac{d\gamma_i}{dp_i}\right) \quad (17)$$

In [17] it is explained that existence and feasibility have the same purpose, so that if the existence of a utility function has been proven, the system will be feasible.

Based on the convergence analysis, this system has converged because it has been proven to meet NE uniqueness through unique fixed points:

1. *Positivity*:

Based on Eq. (6), when value of $a_i/c_i \ll 1$, ${\gamma_i}^{tar} \gg \lambda_k$ and $\lambda_k > 0$ then the nature of positivity will be fulfilled.

2. *Monotonicity*:

Based on Eq. (7), to prove this property, the form $f(p_1) - f(p_2)$ must satisfy the following equation:

$$\frac{\gamma^{tar} + \lambda_k}{g_i}(I_1 - I_2) - \frac{a_i}{c_i{g_i}^2}(p_1I_1 - p_2I_2) > 0 \quad (18)$$

If $p_1 > p_2$ then $I_1 > I_2$ and it is assumed that if $a_i/c_i \ll 1$ then $\frac{a_i}{c_i{g_i}^2} \ll \frac{\gamma^{tar} + \lambda_k}{g_i}$ so that $f(p_1) - f(p_2)$ will be positive, which means that the monotonicity is fulfilled.

3. *Scalability*:

The scalability condition is met for the value of $\alpha > 1$, because of value $f(p_i) - f(\alpha p_i) = \frac{a_i{p_i}^3}{c_i{\gamma_i}^2}(\alpha^3 - \alpha) > 0$. As for α=5 > 0 which means that the scalability is fulfilled.

Based on [20] explained that uniqueness and convergence have the same meaning, so that if the uniqueness of a utility function is proven, the system will converge at one unique fixed point.

4.2 Power and SINR FUE-MUE of proposed PCG method

The initial process of this research is to determine the user pair randomly, both user femto (FUE) and user macro (MUE) as shown in Figure 1. Based on the user distance, the user link gain value can be obtained according to Eq. (2). User SINR calculation refers to Eqs. (3) and (4) for user femto and user macro, respectively. While the user power calculation is carried out using the power update equation in the three methods (Proposed PCG, KG and AG) for all users. The results show that femtocell and macrocell users achieve their respective SINR targets, with power still below the maximum power. This can be achieved if the user's condition is feasible. In this study, the target SINR for each user is distinguished, namely the target SINR for femto users is 5 dB and for macro users is 10 dB.

Based on the simulation, the user power results, both femto users and macro users, reach convergence, as shown in Fig. 4. These results indicate that when the user conditions are feasible, the user power will converge to the optimum power value and reach the target SINR. From Fig. 4, it can be shown that the macro user consumes 4.29 W of power, while the femto user consumes around 0.17 W of power to 1.05 W. The power consumption of user macro is greater than that of user femto because the SINR of the target user macro is greater than the SINR of the target user femto.

Fig. 5 shows the SINR value for both user femto and user macros when they reach convergence. These results show that when it converges, the target SINR can be achieved by all users, both of femto users and macro users according to their respective SINR targets. Femto users have a SINR of 5.496 while macro users have a SINR of 10.04 and all SINR users are able to exceed the target SINR of 5 dB and 10 dB. Along with SINR, Fig. 5 depicts the convergence speed for femto users, which is faster than that for

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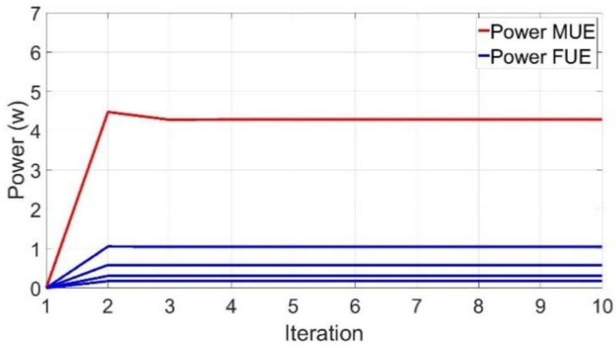

Figure. 4 Power of FUE and MUE for Proposed PCG

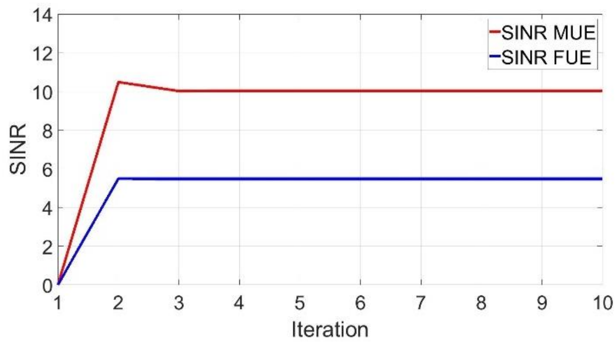

Figure. 5 SINR of FUE and MUE for Proposed PCG

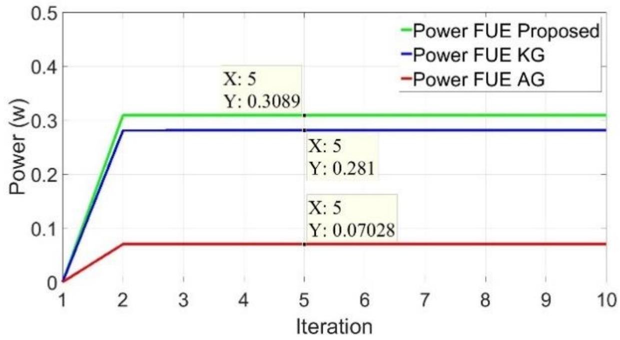

Figure. 6 Comparison of power FUE for all methods

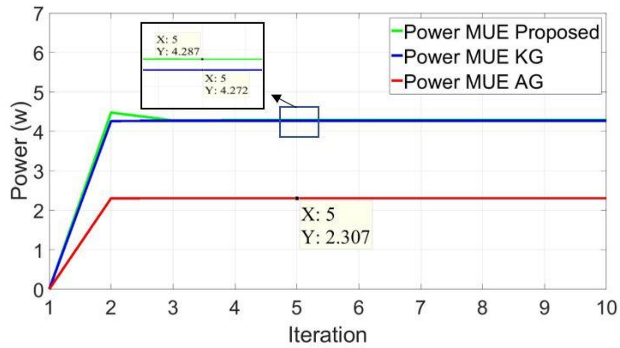

Figure. 7 Comparison of power MUE for all methods

macro users. This is because the user macro's target SINR is greater than the user femto.

4.3 Comparative analysis of the proposed PCG method with other methods

The performance of the system is also shown based on the comparison of power and the achievement of the target SINR by the user using the Proposed PCG method or using other power control methods that also use a game theory approach. Fig. 6 shows the comparison of the FUE power in the Proposed PCG method with two other methods, namely Koskie Gajic (KG) [17] and Al Gumaei (AG) [18]. The results show that when the FUE power reaches convergence, the user using the Koskie Gajic (KG) method has a power of 0.281 W and Al Gumaei (AG) of 0.07028 W. Both power values are smaller than the Proposed PCG method of 0.3089 W. This causes the user SINR obtained by the KG and AG methods to be smaller than the results of the Proposed PCG method.

While Fig. 7 shows the comparison of the MUE power in the Proposed PCG method with two other methods, namely Koskie Gajic (KG) and Al Gumaei (AG). The power on the MUE user on the Proposed PCG is 4.287 W, the KG method is 4.272 W and the AG method is 2.307 W. The results show the same thing as FUE, namely in the KG and AG methods, the MUE power value of the two methods is smaller than the MUE power. on the Proposed PCG method. This has an impact on the achievement of user SINR obtained based on the KG and AG methods which are smaller than the Proposed PCG method.

In addition to the comparison of the power consumed by the user, the performance of the system is also seen based on the achievement of the target SINR by the user, both FUE and MUE measured when using the Proposed PCG method and two other methods, namely the KG and AG methods. The results show that in both the KG and AG methods, all FUE at the time of convergence are only able to achieve a SINR value that is less than the target SINR, which is 5 dB. The results of the KG method SNR of 4.999 dB and AG of 1.251 dB so that both cannot reach the target SINR for FUE. Whereas in Proposed PCG, all FUE at the time of convergence were able to exceed the target SINR value of 5.496 dB. This is as shown in Fig. 8.

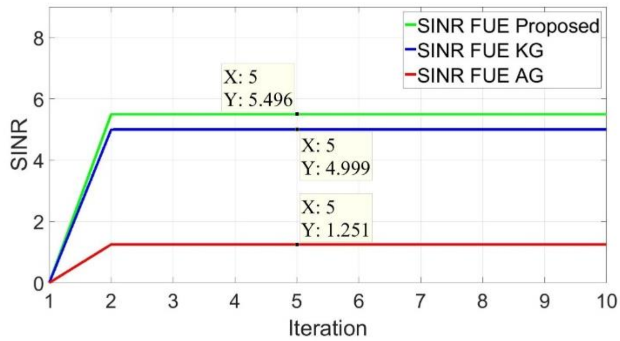

Figure. 8 Comparison of SINR FUE for all methods

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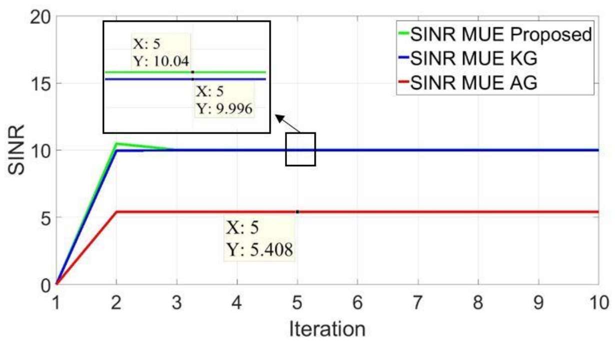

Figure. 9 Comparison of SINR MUE for all methods

Table 1. Comparison of the performance of the proposed PCG, KG and AG methods in terms of consumed power

Performance Parameter of Power	Methods		
	KG	AG	Proposed
Power Consumption for FUE (Watts)	0.281	0.07028	0.3089
Power Consumption for MUE (Watts)	4.272	2.307	4.287

Table 2. Comparison of the performance of the proposed PCG, KG and AG methods in terms of achieved SINR

Performance Parameter of SINR	Methods		
	KG	AG	Proposed
SINR Achievement for FUE (dB)	4.999	1.251	5.496
SINR Achievement for MUE (dB)	9.996	5.408	10.04

Fig. 9 shows the comparison of SINR MUE in the Proposed PCG method and the other two methods, namely the KG and AG methods. The results show that in both of KG and AG methods, all FUE at the time of convergence are only able to achieve a SINR value that is less than the target SINR, which is 10 dB. The results of the KG method SNR of 9.996 dB and AG of 5.408 dB, so that both cannot reach the target SINR for FUE. Whereas in Proposed PCG, all FUE at the time of convergence were able to exceed the target SINR value of 10.04 dB.

When the three methods reached the converge conditions, their performance was generally as summarized in Table 1 and 2. It can be seen from Table 1 that the Proposed PCG consumes slightly more power than the KG method and the AG method, owing to the fact that it is capable of exceeding the specified target SINR.

In Table 2, it can be seen that the effectiveness of Proposed PCG when compared to other methods is that Proposed PCG is able to exceed the given target SINR, both for femto users and macro users, which is 0.496 dB for femto users and 0.04 dB for macro users. This demonstrates the excellent performance of the Proposed PCG in terms of the achieved SINR.

5. Conclusion

Based on the results of the feasibility and convergence tests, the proposed system has been proven to meet the requirements for existence and uniqueness, which are the requirements for meeting the feasibility and convergence of the system. Based on the simulation results, it can be concluded that in all methods, the power consumed by the user macro (MUE) is greater than the power consumed by the user femto (FUE) because the SINR of the target user macro is greater than the SINR of the target user femto. The user reaches the target SINR at convergent power after going through the iteration process based on the power update equation for each method used. The higher the target SINR given, the slower the convergence speed. The simulation results also show that when reaching convergence, users on both femtocell (FUE) and macrocell (MUE) using the Proposed PCG method are able to exceed the specified target SINR, according to the target SINR of each network type. Meanwhile, using the KG and AG methods, neither MUE nor FUE could achieve the target SINR. It can be concluded that the user's SINR at the time of convergence for the Proposed PCG method shows a higher value than the KG and AG methods and is able to exceed the target SINR, so that in achieving the target SINR, the Proposed PCG method is better than the other methods.

Conflicts of Interest

The authors declare no conflict of interest.

Author Contributions

Contributions of author are elaborated as follows. Anggun Fitrian Isnawati: conceptualization, methodology, resources, writing-original draft preparation, funding acquisition, and supervision; Mas Aly Afandi: software, validation, data curation, investigation, project administration, formal analysis, and visualization.

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References

[1] A. T. Leonard, O. A. Nnamdi, O. E. Chiemezie, I. E. Obinna, and E. N. Uchenna, "5G Applications in Heterogeneous Network Issues and Challenges", *IJCSMC*, Vol. 9, No. 9, pp. 94-102, 2020.

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[2] H. Zhang, S. Chen, X. Li, H. Ji, and X. Du, "Interference management for heterogeneous networks with spectral efficiency improvement", *IEEE Wireless Commun.*, Vol. 22, No. 2, pp. 101-107, 2015.

[3] Z. Li, Z. Jiang, Y. Wang, and D. Yang, "A Modified Power Control Scheme in OFDMA Uplink", p. 5, 2008.

[4] X. Li, L. Qian, and D. Kataria, "Downlink power control in co-channel macrocell femtocell overlay", In: *Proc. of 2009 43rd Annual Conference on Information Sciences and Systems*, pp. 383-388, 2009.

[5] V. Chandrasekhar, J. G. Andrews, T. Muharemovic, Z. Shen, and A. Gatherer, "Power control in two-tier femtocell networks", *IEEE Trans. Wireless Commun.*, Vol. 8, No. 8, pp. 4316-4328, 2009.

[6] D. Li, X. Dai, and H. Zhang, "Game Theoretic Analysis of Joint Rate and Power Allocation in Cognitive Radio Networks", *IJCNS*, Vol. 02, No. 01, pp. 1-7, 2009.

[7] I. W. Mustika, K. Yamamoto, H. Murata, and S. Yoshida, "Potential Game Approach for Self-Organization Scheme in Open Access Heterogeneous Networks", In: *Proc. of the 6th International ICST Conference on Cognitive Radio Oriented Wireless Networks and Communications*, 2011.

[8] E. Pertovt, T. Javornik, and M. Mohor, "Game Theory Application for Performance Optimisation in Wireless Networks", pp. 287-292, 2011.

[9] S. Najeh and A. Bouallegue, "Distributed vs centralized game theory-based mode selection and power control for D2D communications", *Physical Communication*, Vol. 38, p. 100962, 2020.

[10] P. Wang, J. Han, F. Liu, Y. Liu, and J. Xu, "A Power Allocation Algorithm Based on Cooperative Game Theory in Multi-cell OFDM Systems", *JNW*, Vol. 6, No. 11, pp. 1610-1617, 2011.

[11] D. Niyato and E. Hossain, "QoS-aware bandwidth allocation and admission control in IEEE 802.16 broadband wireless access networks: A non-cooperative game theoretic approach", *Computer Networks*, Vol. 51, No. 11, pp. 3305-3321, 2007.

[12] A. F. Isnawati, R. Hidayat, S. Sulistyo, and I. W. Mustika, "Distributed power control vs power control game: A comparison study of performance in cognitive femtocell network", In: *Proc. of 2017 International Conference on Applied System Innovation*, pp. 1841-1844, 2017.

[13] A. F. Isnawati and M. A. Afandi, "Game Theoretical Power Control in Heterogeneous Network", In: *Proc. of 2021 9th International Conference on Information and Communication Technology*, pp. 149-154, 2021.

[14] J. Duan, J. Liu, S. Leng, and Q. Wang, "A game-based power control scheme for cognitive radio networks", In: *Proc. of 2012 International Conference on Computational Problem-Solving*, pp. 76-79, 2012.

[15] H. A. Shyllon and S. Mohan, "A Game Theory-based Distributed Power Control Algorithm for Femtocells", In: *Proc. of 2014 IEEE International Conference on Advanced Networks and Telecommuncations Systems*, pp. 1-6, 2014.

[16] F. Li, X. Tan, and L. Wang, "A New Game Algorithm for Power Control in Cognitive Radio Networks", *IEEE Trans. Veh. Technol.*, Vol. 60, No. 9, pp. 4384-4391, 2011.

[17] S. Koskie and Z. Gajic, "A nash game algorithm for SIR-based power control in 3G wireless CDMA networks", *IEEE/ACM Trans. Networking*, Vol. 13, No. 5, pp. 1017-1026, 2005.

[18] Y. A. A. Gumaei, K. A. Noordin, A. W. Reza, and K. Dimyati, "A new power control game in two-tier femtocell networks", In: *Proc. of 2015 1st International Conference on Telematics and Future Generation Networks*, pp. 131-135, 2015.

[19] N. Nie, C. Comaniciu, and P. Agrawal, "A Game Theoretic Approach to Interference Management in Cognitive Networks", *Wireless Communications*, Vol. 143, P. Agrawal, P. J. Fleming, L. Zhang, D. M. Andrews, and G. Yin, Eds. New York, NY: Springer New York, pp. 199-219, 2007.

[20] A. A. Talabani, A. Nallanathan, and H. X. Nguyen, "A Novel Chaos Based Cost Function for Power Control of Cognitive Radio Networks", *IEEE Commun. Lett.*, Vol. 19, No. 4, pp. 657-660, 2015.

[21] R. D. Yates, "A framework for uplink power control in cellular radio systems", *IEEE J. Select. Areas Commun.*, Vol. 13, No. 7, pp. 1341-1347, 1995.

[22] M. Oyakhilome and K. B. Adedeji, "The impact of cell selection on the energy efficiency of heterogeneous networks", *African Journal of Science, Technology, Innovation and Development*, pp. 1-8, 2020.

[23] M. A. Joud, "Pico Cell Range Expansion toward LTE-Advanced Wireless Heterogeneous Networks", p. 89.

[24] A. F. Isnawati, R. Hidayat, S. Sulistyo, and I. W. Mustika, "Channel sharing utility function of power control game in cognitive femtocell network", *Indonesian Journal of Electrical Engineering and Informatics*, Vol. 7, No. 2, pp. 271-278, 2019.

[25] D. T. Ngo, L. B. Le, T. L. Ngoc, E. Hossain, and D. I. Kim, "Distributed Interference Management in Two-Tier CDMA Femtocell Networks", *IEEE Trans. Wireless Commun.*, Vol. 11, No. 3, pp. 979-989, 2012.