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Feasibility Power Control on Cognitive Radio Network with Fixed Power of Primary User

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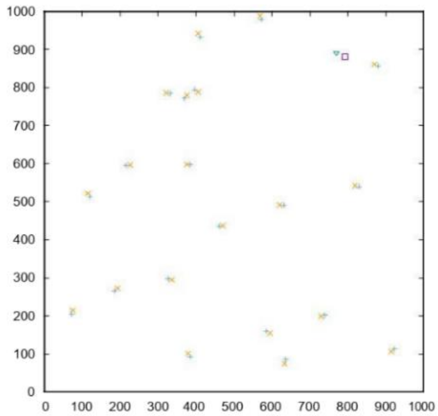
Graphical abstract



Abstract

Frequency spectrum is a limited resource that is strictly determined by static spectrum policy. As every part of the spectrum is already allocated to several certain services, only a portion can be obtained. On the other hand, as the user's demand for reliable communication systems is increasing rapidly, a new paradigm of communication systems is needed. It is compulsory for existing spectrum can handle the increasing number of users, as cognitive radio technology could well address this issue. One crucial key of this technology is its power control. In this paper, the power control based on a feasible solution is studied. The PU has fixed power, the SU power is controlled using the power control method. The non-negative power vector is limited by the initial power P_{max}. The output parameters of this simulation are the FSPC effect to the performance of SU and PU, the SU's P_{max} impact on the feasible solution, and the feasible solution probability. In the P_{max} constraint, the PU SIR rises from 14 dB to 22 dB upon implementing a FSPC. The PU SIR is contrary to the SIR of SU. When the target of the SU's SIR is increased, the SIR value of the PU is decreased. As well as when the P_{max} value of the SU increases, the greater the SIR of the SU, the lower the SIR of the PU. If the power control is feasible, both PU and SU can simultaneously meet the target SIR. Considering the primary user's (PU) power remains fixed, the PU, as the main user, can determine its own power without being influenced by the SU power.

Keywords: *Cognitive Radio, Feasible Solution, Power Control, PU, SU*

Abstrak

Spektrum frekuensi adalah sumber daya terbatas. Karena setiap bagian spektrum telah dialokasikan untuk beberapa layanan tertentu, maka hanya sebagian saja yang dapat diperoleh. Di sisi lain, seiring dengan meningkatnya kebutuhan pengguna akan sistem komunikasi yang andal, diperlukan paradigma baru dalam sistem komunikasi. Spektrum yang ada harus dapat menangani peningkatan jumlah pengguna, karena teknologi radio kognitif dapat mengatasi masalah ini. Salah satu kunci penting dari teknologi ini adalah pengendalian dayanya. Dalam tulisan ini, kontrol daya berdasarkan solusi yang layak dipelajari. PU memiliki kekuasaan tetap, sedangkan daya SU dikontrol menggunakan metode kontrol daya. Vektor daya non-negatif dibatasi oleh daya awal P_{max}. Parameter keluaran dari simulasi ini adalah pengaruh kendali daya solusi layak terhadap kinerja SU dan PU, dampak P_{max} SU terhadap solusi layak, dan probabilitas solusi layak. Dalam batasan P_{max}, nilai rasio sinyal terhadap interferensi (SIR) PU meningkat dari 14 dB menjadi 22 dB setelah penerapan solusi kontrol daya yang layak. PU SIR bertentangan dengan SIR SU. Ketika target SIR SU dinaikkan maka nilai SIR PU mengalami penurunan, dan ketika nilai P_{max} SU bertambah, semakin besar SIR SU maka semakin rendah SIR PUnya. Jika kendali daya memungkinkan, PU dan SU dapat memenuhi target SIR secara bersamaan. Mengingat daya PU tetap, maka PU dapat menentukan dayanya sendiri tanpa terpengaruh oleh SU.

Kata kunci: Radio Kognitif, Kontrol Daya, PU, SU

1. INTRODUCTION

Cognitive radio networks (CRNs) are pivotal in addressing the challenges of spectrum scarcity and inefficient spectrum utilization in wireless communications. By intelligently sensing and adapting to the radio environment, CRNs enhance the efficiency of spectrum use, thereby improving service quality and enabling a wide range of applications. CRNs can detect unused frequency bands, known as spectrum holes, allowing them to dynamically switch channels to avoid congestion and enhance overall spectrum efficiency [1]. This adaptability is crucial in environments with high demand, such as urban areas, where traditional fixed spectrum allocations often lead to underutilization of available resources [2].

CRNs play a significant role in crisis communication by ensuring reliable signal transmission during disasters, which is vital for effective recovery efforts [3]. The integration of various transmission methods, such as UAVs, can further optimize communication efficiency in critical situations [3]. As part of the 5G revolution, CRNs utilize advanced spectrum sensing techniques to minimize interference and optimize energy consumption, thus supporting the growing demand for connected devices [4][5]. These networks facilitate the digitization of clean energy infrastructure, promoting sustainable practices in wireless communication [3]. CRNs significantly enhance spectrum efficiency through dynamic spectrum management, advanced sensing techniques, and innovative algorithms. By allowing secondary users to opportunistically access underutilized spectrum, CRNs optimize bandwidth usage and improve overall network performance.

CRNs enable secondary users to exploit unused licensed channels, thereby alleviating spectrum scarcity. This opportunistic access allows for greater bandwidth availability for mobile users, enhancing data transmission rates [6]. The integration of reconfigurable intelligent surfaces (RIS) with CR technology further optimizes spectrum management, improving signal coverage and efficiency in spectrum detection [7]. Techniques such as the Multi-Objective Improved Salp Swarm Algorithm (MOISSA) enhance spectrum sensing performance by optimizing throughput, energy efficiency, and interference management [8]. Cooperative spectrum sensing methods improve reliability and energy efficiency, allowing CRNs to adaptively manage spectrum resources while minimizing the impact on primary users [9]. Hybridized handover techniques in CRNs reduce power consumption and enhance data rates, contributing to overall system throughput [10]. The use of fuzzy decision-making systems for channel selection and switching further boosts performance metrics like packet delivery ratio and latency [6].

While CRNs present a promising solution for spectrum efficiency, challenges such as interference management and the need for robust sensing algorithms remain critical for their successful implementation in real-world scenarios. Power control techniques play a crucial role in mitigating interference in crowded cognitive radio networks by optimizing transmission power levels to protect primary users while maximizing secondary user performance. These techniques leverage various strategies to ensure efficient spectrum utilization.

Different algorithms have been used in research on power control in CRNs, mobile communication systems, and satellite communication systems. The power control mechanism is proposed in [11-23]. A combined scheme of interference channel learning and centralized power control based on the adaptive coding and modulation (ACM) protocol is proposed in [11]. Channel Assignment and Power Allocation are proposed in [12] and [13]. An effective power allocation algorithm with smart array antennas and non-orthogonal multiple access is presented in [14]. A distributed power control algorithm is proposed in [15] to solve the global energy efficiency (GEE) maximization problem, provided that a minimum target SINR is satisfied for every UE in wireless cellular networks.

Power control CRNs based on the Game Theoretic Approach, Hybrid PSO, are studied in [16] and [17]. Critical insights on power control schemes and high EE operation are studied in [18] in order to maximize the performance of UD CF-mMIMO systems. The process of carefully regulating a transmitter's power in order to raise everyone's quality of service (QoS) is known as power control. In [19], a proposed MAC protocol called rate-aware power-controlled channel assignment (RPCCA) is presented. In addition to batch-based simultaneous channel assignment decisions to rival SUs and power control to prevent mutual interference, it takes into account the varying demand rate amongst SUs. Power control mechanisms in CRNs are essential for efficient spectrum utilization and interference management. Various studies have proposed distributed, cooperative, and game-theoretic approaches

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to address power control challenges in cognitive radio systems, aiming to optimize network performance while ensuring seamless coexistence with primary users.

Adaptive Power Control (APC) technique dynamically adjusts transmission power based on the requirements of cognitive users and monitors primary user power to minimize interference, achieving a 32% reduction in delay and an 11% increase in throughput [20]. By modeling the network as a non-cooperative game, users can optimize their power levels to enhance signal-to-interference-plus-noise ratio (SINR) while maintaining low power consumption [21]. Distributed Power Control strategy employs a virtual electricity price game to manage co-tier interference, ensuring quality of service for primary users [22]. Advanced methods Deep Learning Techniques utilize deep learning to adaptively determine optimal power levels, addressing the complexities of inter-user interference and QoS constraints [23].

Although there are many methods, power control is not free from the issue of feasible systems. A feasible system can drive towards high efficiency, has the potential for optimal performance, and at the same time prevents the system from failing in power control. In an infeasible system, each user adjusts their power without realizing that it is impossible to simultaneously meet SIR requirements, leading to higher transmission power during power control [24]. Therefore, knowledge about feasible systems is necessary for the implementation of power control.

Power control has been implemented in [25] and [26] based on the feasible solution of the CRNs. In order to reduce energy consumption, the feasible system is optimized depending on channel selection [25]. When users on the same channel modify their transmission power to enhance the link quality, they can achieve the predetermined SIR target. However, the performance of the PU was not taken into account in [25] or [26], therefore its performance as the higher priority substance is not certain.

In paper [27-29], power control based on the feasible solution is already considered the existence of the PU. However, the performance of the feasible solution in [28] is not described in detail. They only evaluate the signal-to-noise ratio (SINR) performance of the SU and do not discuss how the feasible solution influences the transmission power. In [28], the autonomous distributed power control is proposed. The distributed power control scheme can be obtained by applying an iterative algorithm to solve the feasible solution equation. In [29], the PU is also a controlled transmission power. The difference between [28] and [29] is in the transmission power of PU. In [30] and [31], power control methods are used concurrently with channel assignment. Power control and channel assignment are used simultaneously, not sequentially. In the same environment, many transmissions with minimal interference may operate concurrently across each idle channel due to the power-controlled channel assignment. This protocol is based on solving a series of linear equations to calculate the power required on each idle channel. In [31], user scheduling is also implemented. Transmission power control, appropriate channel assignment, and user scheduling in CRN can greatly improve spectrum utilization and overall network performance. Our paper focuses on power control methods, where the presence of PUs is considered. PU power is made fixed, not controlled simultaneously with SU power so that higher priority primary users can determine their power.

In this paper, the feasible solution of power control (FSPC) is studied by considering the existence of PU. The existence of the PU is important for both SU and PU to utilize the spectrum together with no harmful interference. Furthermore, the performance of the PU that has a higher priority could be maintained. PU has a fixed power, whereas SU's power is controlled based on the feasible solution power control. If there is a non-negative power vector, a feasible solution is achieved, and if the feasible solution is achieved, the SU receiver will meet the SIR target.

2. METHODS

2.1 System Model

N transmitter-receiver pairs of the secondary user (SU) and one pair of transmitter-receivers of the primary user (PU) define the system model of the simulated CRNs, as shown in Figure 1. PU and SU are located in the same area, where PU is in the middle, whereas SU is randomly located around PU at a certain distance. The research flowchart can be seen in Figure 2.

It is considered that both users are on the same channel, causing the SU transmitter to interfere to the PU receiver. Furthermore, each of SU receiver would be interfered by the transmitter of the PU or another SU transmitter. Because we consider the simultaneous transmission, the calculation of PU SIR can be represented in (1).

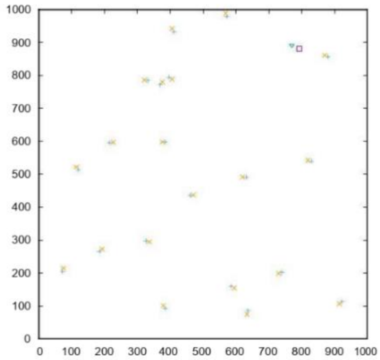

Figure 1. CRN's topology

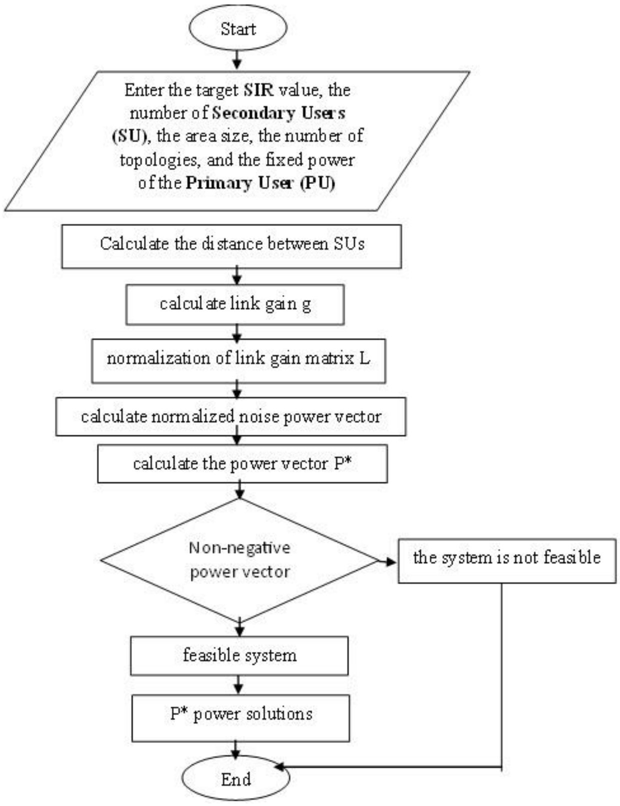

Figure 2. Research Flowchart

$$\gamma_i{}^{pu} = \frac{G_{ii}^{pu} p_i^{pu}}{\sum_{j=1}^{N} G_{ij}^{pu,su} p_j^{su} \delta_{c_i c_j} + n_0} \tag{1}$$

While the SIR of SU receiver can be expressed in (2).

$$\gamma_i{}^{su} = \frac{G_{ii}^{su} p_i^{su}}{G_{ij}^{su,pu} p_j^{pu} \delta_{c_i c_j} + \sum_{j=1, j\neq i}^{N} G_{ij}^{su} p_j^{su} \delta_{c_i c_j} + n_0} \geq \gamma_{su}^{target} \tag{2}$$

The transmit power for the i^{th} Tx SU is p_i^{su}, and the transmit power for the j^{th} Tx SU is p_j^{su}. Link gain between j^{th} Tx SU and i^{th} Rx PU are represented by $G_{ij}^{pu,su}$, link gain between j^{th} Tx PU and i^{th} Rx SU are represented by $G_{ij}^{su,pu}$. G_{ij}^{su} is a link gain between j^{th} Tx SU and i^{th} Rx SU. Tx is for Transmitter dan Rx is for Receiver. $\delta_{c_i c_j}$ is the interference function that indicates whether the channel interference c_i and channel c_j are the same, if $c_i = c_j$, $\delta_{c_i c_j} = 1$, otherwise, $\delta_{c_i c_j} = 0$.

2.2 FSPC with The Primary User

From the quality of service (QoS) requirements for the SU in (2), SIR equation above can be written as (3).

$$P_i > \gamma_{target}^{su} \left(\sum_{j=1, j\neq 1}^{N} \frac{g_{i,j}}{g_{i,i}} P_j + \frac{g_{i,pu}}{g_{i,i}} P_{pu} + \frac{N_o}{g_{i,i}} \right) \tag{3}$$

The lowest transmission power of the i^{th} SU needed for dependable communication is shown in (3). To represent (3) using matrix notation, defined $N \times N$ matrix, so $h_{i,j}$ in H is shown in (4).

$$h_{i,j} = \begin{cases} \gamma_{su}^{target} \dfrac{g_{i,j}}{g_{i,i}}, i \neq j \\ 0, i = j \end{cases} \tag{4}$$

and $N \times 1$ vector U

$$u_i = \gamma_{su}^{target} \frac{g_{i,pu} p_{pu}}{g_{i,i}} + \gamma_{su}^{target} \frac{N_0}{g_{i,i}} \tag{5}$$

Then, linear inequality in (3) can be written as (6).

$$P_i \geq \sum_{j=1}^{N} h_{i,j} P_j + u_i \tag{6}$$

Consequently, matrix notation from linear inequality is expressed in (7).

$$(I - H)P \geq U \tag{7}$$

where I is the identity matrix N x N, and P is the vector of transmission power. If the maximum eigenvalue of the matrix H is less than 1, there is a non-negative power vector P which meets (7). Thus, the SIR target of SU is reached. In that case, the Pareto optimal power vector is shown in (8).

$$P^* = (I - H)^{-1} U \tag{8}$$

In practical implementations, the maximum transmission power is limited by (9).

$$0 \leq P_i \leq P_{su}^{max} \tag{9}$$

3. RESULTS AND DUSCUSSION

In this section, a power control solution on CRNs with the existence of PU is simulated. PU has fixed power, whereas the power of SU is controlled. Simulations performed to see power and SIR of SU and PU after implementation of power control, the effect of P_{max} of SU to a feasible solution, and the probability of the feasible solution. There are 21 users, which consists of a PU and 20 users of SU. PU and SU are randomly distributed on a rectangular area with dimensions $1{,}000 \times 1{,}000$ m, as shown in Figure 1. Each receiver will encounter interference from other transmitters since it is expected that all nodes use the same channel for operation. The simulation parameters are shown in Table 1, where the maximum transmission power of PU is P_{max}^{pu} = 25 mW and maximum transmit power of SU is P_{max}^{su} = 0.15 mW; 15 µW. In the simulation, the effects of fast fading and shadowing are not taken into account. The noise power is 10^{-13}, path loss model that used is free space, and path loss exponent = 2.

Table 1. Simulation Parameters

Parameters	Values	Parameters	Values
Simulation area	10	Noise power	10^{-13}
Numbers of PU	1	P_{max} PU	25 mW
Numbers of SU	20	P_{max} SU	0.15 mW; 15 µW
Numbers of channel	1	Target of SIR of SU	7 dB
Pathloss exponent	2	Numbers of topology	535

3.1 Power and SIR at the FSPC

Initial power of PU is 25 mW, the initial power of SU is 0.15 mW, and target SIR of SU is 7 dB. In Figure 3, it can be seen power at initial power (P_{max}) SU and power vector of a power control solution. If an FSPC exists, the power of SU varies to achieve the SIR target. A feasible solution is achieved when the power vector is non-negative.

From Figure 4, it can be observed that at the initial power level, the received SIR of SU varies for each node. This is because the amount of interference power that each node receives from its nearby nodes varies.

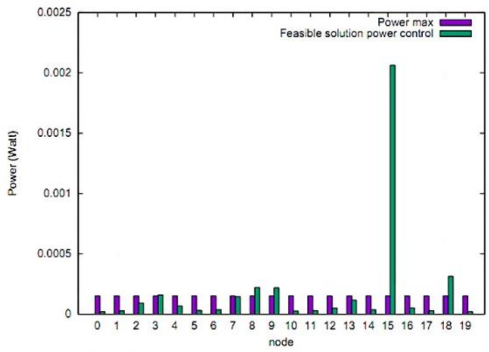

Figure 3. Power P_{max} of the SU and FSPC

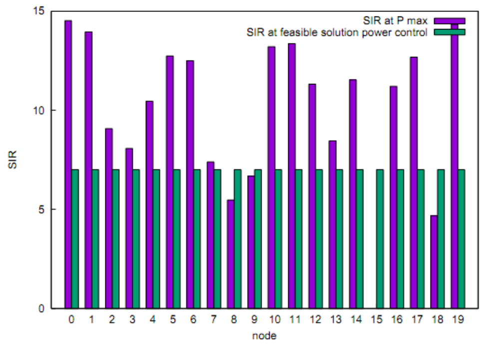

Figure 4. SIR of the SU with a feasible solution P_{max} and power control

If without FSPC, all SU powers are the same, which is 0.15 mW (Figure 3). The result is that out of 20 SUs, 16 SUs have SIRs exceeding the target. There are 4 SUs with SIRs below the target. Without FSPC, not all SUs can meet their SIR targets (Figure 4). During FSPC, for the 15th SU, there is a significant increase in power, from 0.15 mW to 0.002 W (Figure 3). This happens because the SU needs to increase its power to achieve the desired SIR target.

A node's SIR performance will dramatically decline if it receives excessive interference from other nodes, which could lower the quality of a communication signal. Power control methods can address this issue by adjusting power to maintain SIR performance. In a feasible solution power control, if the system is feasible, each SU will achieve the target SIR. In Figure 4, it is evident that the SIR for SUs in the feasible solution power control is 7 dB at each node. This means that all SU receivers meet the target SIR.

The transmission power can be lower than the initial power (P_{max}) using power control, and the SU receiver can achieve the SIR target. This power reduction also affects the SIR of PU, where the received interference of PU is reduced. For PU, the SIR at initial power is 14.0428 dB while the SIR of PU after power control is 22.4656 dB. After power control, the SIR of PU increased due to the reduction of PU received interference.

3.2 Power and SIR at Power Control with P_{max} Constraint

Initial power of PU is 25 mW, initial power of SU is 0.15 mW. In this simulation, the power vector is limited by initial power (P_{max}). If the power exceeds P_{max} of the SU, then the power is set to be P_{max}. Power of SU at initial power P_{max} and at the FSPC with P_{max} constraint can be seen in Figure 5. At initial power, SU has the same power, *i.e.* 0.15 mW, while when an FSPC implemented, the power of SU is 0.15 mW and lower.

At the FSPC that limited by P_{max}, not all SU achieve the SIR target. At Figure 6, it can be seen that there is an SU node that receives SIR below the SIR target that has been determined. This indicates that the performance of the SU decreased when compared to the FSPC without P_{max} constraint. Compared to the previous paper [29], this study shows that after FSPC, there are SUs that do not meet their SIR targets. In paper [29], during FSPC, all SUs achieved SIRs above the target. This is because, in this study, the power of the PU remains constant and is not controlled or adjusted. Although the SU performance decreases, the SIR of PU is increased. Good performance of PU is preferred because PU has a higher priority in accessing the frequency spectrum. The existence of SU should not interfere PU, so power control of SU should not degrade the performance of PU.

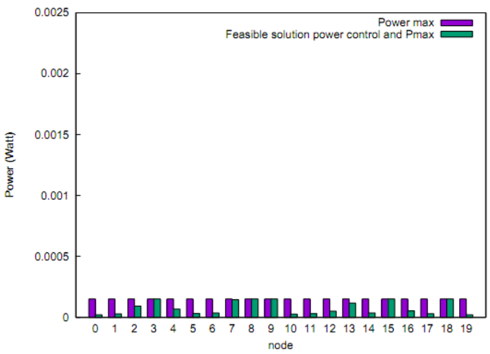

Figure 5. Power of the SU at P_{max} and feasible solution of the power control with P_{max} constraint

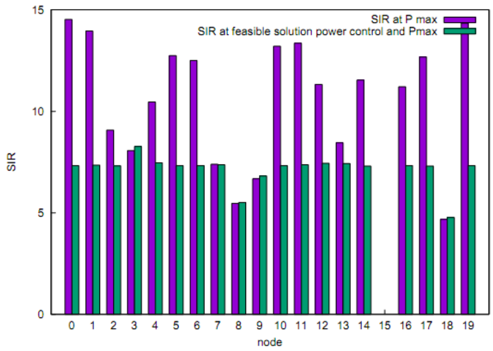

Figure 6. SIR of the SU at initial power and feasible solution of the power control with P_{max} constraint

At initial power, which is the power of SU is 0.15 mW, the SIR of PU is equal to 14.0428 dB. At power control, the SIR of PU is 22.525 dB, as seen in table 2. It is caused by the power of SU are under P_{max}. In Figure 5, it can be seen that from 20 nodes of SU, 14 nodes have power under P_{max}. This power reduction caused interference to PU reduced so that the PU SIR is increased.

Table 2. The Effect of the SU's Power to SIR of PU

Intitial Power	Feasible Solution	Feasible Solution with $\boldsymbol{P_{max}}$
14.0428 dB	22.4656 dB	22.525 dB

3.3 Average of User's SIR

This simulation shows the effect of P_{max} of SU on the performance of PU and SU. P_{max} of SU is simulated by 1.5×10^{-5} W and 1.5×10^{-4} W. SIR target of SU is 7 dB. If a feasible solution exists, the power of SU varies to meet the SIR target. In cases where the intended node pairs distances are far while the node close to neighboring nodes, the nodes require high power to achieve its target of SIR. In order to an SU, a node does not radiate too high power so it does not interfere performance of SU and PU, the SU power should be limited by P_{max}.

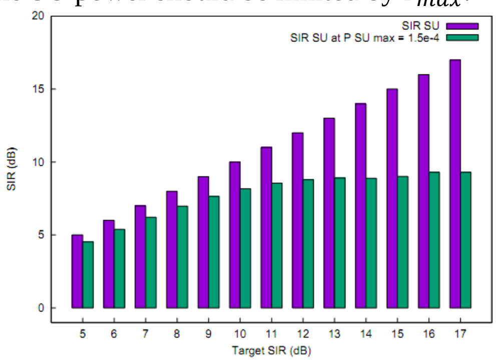

Figure 7. Average value of the SU's SIR at feasible solution and at FSPC with P_{max} constraint

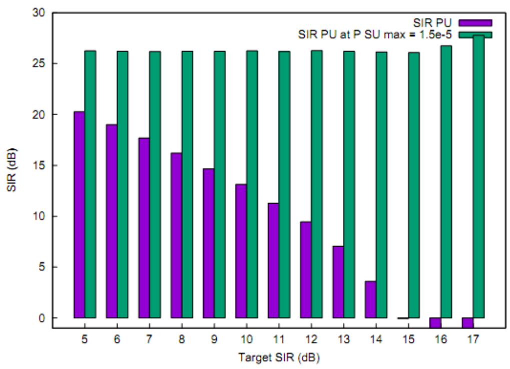

Figure 8. Average value of PU's SIR at feasible solution and at FSPC with P_{max} constraint

In Figure 7, it can be seen that with the FSPC, each node of SU receives SIR in accordance with the target. At FSPC that is limited by P_{max}, the average of SU's SIR smaller while the average SIR of PU larger than the feasible solution that is not limited by P_{max} (see Figure 8). It is caused by the received interference of PU reduced.

It is applied to P_{max} SU = 1.5×10^{-4} W and P_{max} SU= 1.5×10^{-5} W. At P_{max} SU = 1.5×10^{-5} W, the SIR of SU decreased while the SIR of PU increased significantly, as seen in Figure 10. This indicates that the smaller of SU's power, so interference from SU to PU is getting smaller, so that the SIR of PU is greater.

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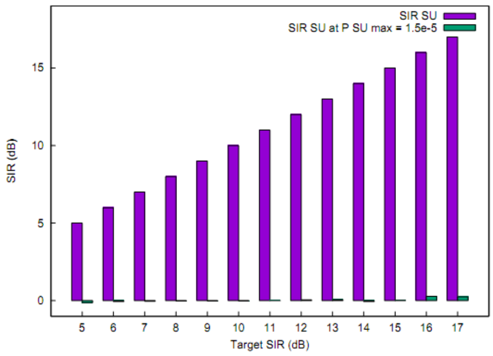

Figure 9. Average value of the SU's SIR at feasible solution and at FSPC with P_{max} constraint

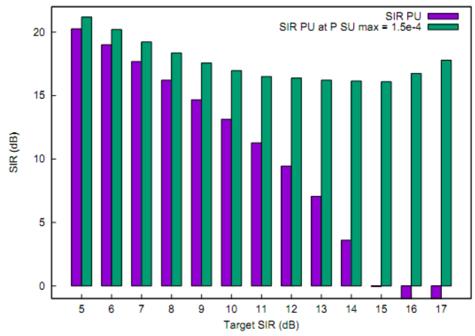

Figure 10. Average value of PU's SIR at feasible solution and at FSPC with P_{max} constraint

In Figure 7, it can be seen that the average of SU's SIR at P_{max} = 1.5 × 10^{-4} W larger than the SIR of SU when P_{max} = 1.5 × 10^{-5} W, as seen in Figure 9. We can see that the higher SIR target of SU, the SIR of PU is decreased.

3.4 The Probability of Feasible Solution Power Control

The probability of a feasible solution can show the number of the feasible topology of the entire topology. In this simulation, the total topology is 1,000. The probability of a feasible solution is seen from different SIR targets of SU. The larger the SIR target of SU, the probability of feasible decreases, as depicted in Figure 11. This is because the larger the SIR target of SU, the greater the power required. The greater power causes interference to neighbor nodes. The greater interference causes the transmitter of SU to raise its power in order to achieve the SIR target. This condition can cause the system is not feasible.

In this simulation, it can be seen that the topology is not feasible on SIR target more than 17 dB, while all topology feasible on SIR target less than or equal to 5 dB.

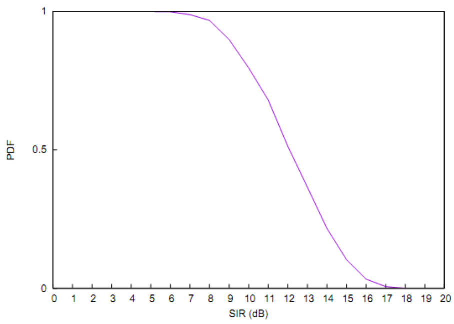

Figure 11. The probability of feasible topology

4. CONCLUSION

A system is feasible if the power vector is non-negative. with an FSPC, the SIR of the SU meets the SIR target. The FSPC can improve the both performance of SU and PU. with an FSPC, the SIR of the PU increased from 14 dB to 22 dB. calculation of power at the FSPC and SIR of SU consider the interference of PU to SU. interference was not only from other SU but also from PU. The performance of the PU is better with an FSPC with P_{max} constraint. It caused interference to PU decrease so the SIR of PU increases. The effect of SU on the performance of PU is the higher SIR target of SU, SIR of PU is decreased. If the power control is feasible, both primary and secondary users can simultaneously meet the target SIR. As a result, signal quality and channel capacity can be improved. Considering the primary user's (PU) power remains fixed, the PU, as the main user, can determine its own power without being influenced by the secondary user's (SU) power.

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