A Spectrum Sharing Criterion Based on Capacity Conservation Ratio of Primary User

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***Abstract*—This paper presents a spectrum sharing criterion for protecting the capacity of the primary terminal with various signal-to-noise ratio (SNR). The proposed criterion determines allowable interference toward the primary system based on a capacity conservation ratio (CCR). The CCR is a ratio of the capacity of the primary terminal without the secondary user interference and that with the secondary interference. The performance of the primary terminal with high capacity can be maintained to a high level with keeping the CCR. On the other hand, the performance of the terminal with low capacity also can be maintained to a small capacity degradation by using the same CCR. In addition, a power control method of the secondary system based on CCR is proposed. Secondary system can achieve increasing on its own capacity and can avoid the interference toward the primary system using this method. However, the proposed method cannot avoid the interference when the location information of the primary and secondary terminals has a large error. In order to solve this problem, we consider a power control method, which consider the location error based on worst case scenario of the terminal location.**

I. Introduction

Wireless communication systems require improving the spectrum utilization efficiency in order to solve the shortage problem of the frequency resources. In the current radio regulations, to avoid a harmful interference to the other systems, spectrum resources exclusively allocated to the primary systems. However, total frequency utilization efficiency is not high by considering uneven distribution of utilization time and area. A spectrum sharing system over the unused primary allocated band (White Space), which results due to the uneven distribution of spectrum utilization, can improve the spectrum efficiency. Many researches attract attention to the spectrum sharing between different wireless systems as one type of system using the cognitive radio technology to improve the spectrum utilization efficiency drastically[1]. A cognitive radio is able to change the communication method, modulation method, signal frequency, data rate and so on, according to the surrounding wireless environment. It became possible to share the spectrum among the different wireless systems without giving large effect to the primary system by giving different priority to the systems.

In the spectrum sharing between different systems, a primary system which has been originally allocated to the spectrum band is given a high priority, and a secondary system shares the same spectrum with a lower priority by the condition of protecting the giving interference toward the primary system.

In such system, the achieved capacity of the secondary system under the constraint of protecting the primary system is important. Some previous researches have been studied for calculating the achievement capacity of the spectrum sharing system [2]-[4]. These researches are intended to increase the achieved capacity of secondary system with avoiding the interference toward the primary system. The external information from the server can be used for improving the spectrum sharing performance for controlling the transmit power with avoiding the large interference.

The spectrum sharing by using service area information of the primary system has been proposed in [2]. This method considers a TV service as a primary system. Secondary system utilizes a server information of the location of TV broadcasting tower, the transmission power and the service area of TV, and decides the communication parameters. It considers their own location information using Global Positioning System (GPS) before starting transmission to share the spectrum. A secondary terminal decides the transmit power to keep the signal-to-interference ratio (SIR) at the primary receiver, assuming the location at the nearest area edge using the external information. Moreover, the spectrum sharing method by using location information of the primary receiver has been proposed in [3]. In this system, a secondary system obtains location information from the sever like method shown in [2]. Antennas of Satellite communications system are anchored in the position, thus secandary terminal can obtain accurate location information of primary terminals. Secondary terminal can decide the transmit power by estimating the interference toward location estimated primary terminals. This transmit power is calculated by the allowed interference power at the primary which is decided by considering a margin form thermal noise and propagation loss. Therefore, the interference from the secondary system can be protected at each primary terminal.

However, these methods have many problems. The method in [2] requires non overlapping the secondary area with primary area. This problem can be solved by using location information of the primary terminal as proposed in [3]; however it remains possibility that the secondary terminal cannot protect the primary receiver in all locations or time if SNR of the primary changes with the location and time. In addition, two methods do not consider assessment of accuracy external information for spectrum sharing. If the secondary system uses less-accurate information, secondary terminal cannot avoid the harmful interference toward the primary receiver due to error effect. It is difficult to obtain external information without error. Therefore, a method of spectrum sharing considering error of external information for reliable protected primary system with information error is required.

This paper considers spectrum sharing systems between a primary system and a secondary system while overlapping over each other. We assume the primary system is a cellular system in which the SNR of the primary terminal changes due to the different terminal location. Here, we propose a spectrum sharing criterion and a power control method based on a CCR. The proposed criterion and the proposed method realize increasing the achievable capacity of the secondary system with avoiding the interference toward the primary system. The proposed power control method requires the location information of each terminal; however it is difficult to obtain the information without error. In order to solve above problem, this paper also proposes a power control with considering the error of the location based on worst case scenario .

This paper is organized as follows. Section II proposes spectrum sharing criterion. A power control method based on CCR is proposed in Section III. Section IV considers error effect and proposes counter measure. Section V presents simulation results, and conclusions are drawn in Section VI.

II. Spectrum Sharing Criterion

A secondary system requires performing communication in licensed primary bands with avoiding the interference toward the primary system. In order to achieve a spectrum sharing while protecting the primary system, we have to set a clear spectrum sharing criterion. The secondary system should decide its communication ability and parameters under the primary bands based on this criterion. In the conventional primary and secondary system, secondary system is required only limit the interference power toward the primary system. However, this limitation cannot keep the performance of the primary system if the desired signal level at the primary receiver is changed due to the location of the primary receiver.

Spectrum sharing criterion based on limiting the interference power toward the primary is proposed in [4]. This criterion has advantages that it is relatively easy to achieve the criterion for secondary system. However, if SNR of the primary system changes significantly, secondary system cannot avoid harmful interference toward the primary terminal whose SNR is low. In order to keep the performance of the primary system by above situation, the transmit power of secondary terminal is limited to reduce the interference power. Then the secondary system cannot achieve good communication performance because the excess margin for transmit power is required for secondary terminals.

Other criterion requires keeping primary SIR by controlling the secondary transmit power and parameters proposed in [2]. This criterion can protect low SNR primary terminals due to restricting the interference of the primary system based on the received signal power of the primary system, even if the SNR of the primary system changes significantly. However, this method has a high possibility that the existence of the secondary system degrades the Signal to Interference-plus-Noise power Ratio (SINR) of the primary terminal with achieving criterion. The criterion should set the required SIR high to protect the primary terminal which has high SNR, thus restrictions on secondary tighten.

It is hoped to increase the highest and the lowest throughput in the service area. However, the secondary system cannot avoid the harmful interference toward either high or low SNR primary terminal by using conventional criterions for spectrum sharing. To solve these problems, a criterion should preserve the capacity under both high SNR and low SNR primary terminals. In the conventional citerions, protecting of high impact primary terminal is the excess protection from low inmpact primary terminal. The excess protecting has consequence that secondary system cannot increase the chance of the transmit opportunities or the transmit power, thus the enabling criterion to protect the primary terminal with treating the various SNR is the best.

Therefore, in this paper, we propose a novel definition of the primary performance protection based on a CCR under a spectrum sharing environment for avoiding the interference toward the different SNR primary terminals due to the different location. The CCR is a ratio of the capacity of the primary terminal without interference from the secondary terminal and that of the decreased capacity with the interference.

The performance of the terminal with high capacity can be maintained to be a high level with keeping the CCR. On the other hand, the performance of the terminal with low capacity also can be maintained to be small capacity degradation by using the same CCR.

The proposed criterion based on CCR is defined by

$$\Pr\left[\frac{C}{C_0} \leq \alpha\right] \leq \beta, \tag{1}$$

where C_0 [bps/Hz] is capacity of the primary terminal without interference from the secondary terminal, C [bps/Hz] is decreased capacity of the primary terminal with interference, α is allowable minimum CCR and β is probability of dropping CCR below α. A change in the capacity of primary terminal with restricting interference from the secondary terminal based on the proposed criterion is shown in Fig. 1. Fig. 1 shows that the criterion based on CCR can protect the different capacity terminals.

III. Power Control Method Based on Capacity Conservation Ratio

The proposed criterion based on CCR defines allowable ratio of decrease in the capacity of the primary receiver

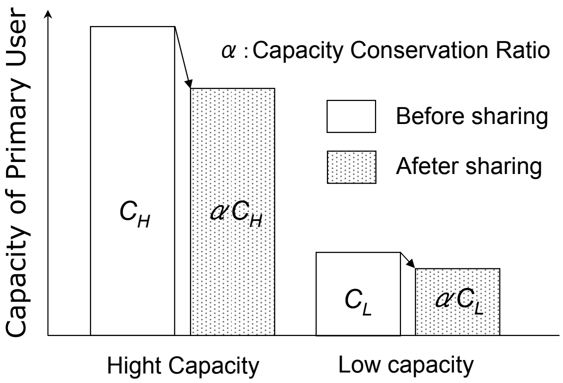

Fig. 1. Change of the capacity for keeping CCR.

terminals. The secondary terminal is required to transmit with low power when the SNR is low at the primary terminal. On the other hand, the secondary terminal is permitted to transmit with comparative high power, if the SNR is high at the primary terminal. This paper proposes a power control method exploiting property of allowable interference for improving the capacity of the secondary system with avoiding the interference toward the primary terminal. In the proposed power control method, the secondary terminal estimates the capacity C_0 of the primary terminal using external information from the server. Furthermore it controls the transmit power to keep the ratio of the capacity without secondary, C_0 and capacity with the secondary, C to be higher than the required α by criterion.

This paper considers the primary system which has several capacities according to the location of the primary receiver, and secondary transmitter whose communication distance is short. In the spectrum sharing system, the primary system registers information of the system parameters on the server that provides external information to secondary systems. In addition, we assume that the channel information is registered on the server. When the secondary terminal want to transmit the signal, it checks external information for power control as follow:

- Carrier frequency
- Transmit power of primary system
- Location information of primary terminal
- Location information of primary base station (BS)
- Wireless channel model

The secondary terminal controls the transmit power using the external information. In order to determine the allowable interference power $I_{\text{allow,dBm}}$[dBm], the secondary terminal obtains the received signal power of the primary terminal $P_{\text{rx,pri,dBm}}$[dBm]. $P_{\text{rx,pri,dBm}}$[dBm] is calculated as

$$P_{\text{rx,pri,dBm}} = P_{\text{tx,pri,dBm}} - L_{\text{path,pri}}, \tag{2}$$

where $P_{\text{tx,pri,dBm}}$[dBm] is the transmit power of the primary system and $L_{\text{path,pri}}$[dB] is the estimated path loss between the primary BS and the primary terminal based on their locations.

Next, the secondary terminal calculates $I_{\text{allow,dBm}}$ to satisfy the criterion from estimated primary received power $P_{\text{rx,pri,dBm}}$ and the noise floor $N_{\text{pri,dBm}}$[dBm]. The minimum allowable CCR α and $I_{\text{allow,dBm}}$ are linked by the inequality expression as:

$$\frac{\log_2\left(1+\frac{P_{\text{rx,pri}}}{I_{\text{allow}}+N_{\text{pri}}}\right)}{\log_2\left(1+\frac{P_{\text{rx,pri}}}{N_{\text{pri}}}\right)} \geq \alpha, \tag{3}$$

where $P_{\text{rx,pri}}$[mW], N_{pri}[mW] and I_{allow}[mW] are changing unit of $P_{\text{rx,pri,dBm}}$, $N_{\text{pri,dBm}}$ and $I_{\text{allow,dBm}}$ from dBm to mW. This equation (3) is transformed to I_{allow} as,

$$I_{\text{allow}} \leq \frac{P_{\text{rx,pri}}}{\left(1+\frac{P_{\text{rx,pri}}}{N_{\text{pri}}}\right)^{\alpha}-1} - N_{\text{pri}}. \tag{4}$$

The secondary terminal estimates the path loss between the primary terminal and the secondary terminal as $L_{\text{path,sec}}$[dB] by using the location information of the primary terminal and own location information under GPS. Then, the allowable transmit power $P_{\text{tx,sec,dBm}}$[dBm] is given by

$$P_{\text{tx,sec,dBm}} = I_{\text{allow,dBm}} + L_{\text{path,sec}}. \tag{5}$$

The secondary terminal controls the transmit power below $P_{\text{tx,sec,dBm}}$, and begins transmitting the signal.

In this paper, we utilize the path loss model which is given by,

$$L_{\text{path}}(d) = -10\log_{10}\left(\frac{\lambda}{4\pi d_0}\right)^2 + 10n\log_{10}\left(\frac{d}{d_0}\right), \tag{6}$$

where λ is the wavelength of the carrier frequency and d is the communication distance.

IV. Power Control Method Considering Location Error

In the proposed power control, the secondary terminal determines transmit power using the location information of the primary base station, the primary receiver and the secondary terminal. Since obtaining the location information without error from GPS is very difficult, we should consider the effect of the location information with error. When the location information has error, the secondary terminal cannot exactly determine the allowable transmit power avoiding the interference toward the primary system with keeping the criterion of primary protection. Then, we propose a power control method considering the error of location information. In this paper, we assume the location information of the primary BS has no error because BS is setting on the fixed position. We also consider the secondary system is a small area point to multi-point system with BS and mobile terminals, so that we assume the secondary BS also does not have location information error.

In spectrum sharing with location error, the secondary system is required to estimate the location error and set the margin for transmit power to reduce the probability of giving harmful interference as β or less. The secondary terminal sets the probability of miss protection of the primary terminal at β. We consider the worst case for restricting the error. It is required to know the error distribution. Here, we suppose that the error distribution is two-dimensional Gaussian distribution and the secondary system has knowledge of this distribution. Two-dimensional Gaussian random vectors with mean 0, and variance σ^2, radius of the circle a account for $1-\xi$ is given by equation (7). We consider the effect of location error by using this circle for restricting error distribution to estimate the received interference power of the primary terminal.

$$a = \sqrt{2\sigma^2 \left|\ln \xi\right|} \tag{7}$$

The secondary terminal determines the allowable transmit power based on the location information of the primary terminal. The error in the location information impacts the estimation of the received signal power at the primary terminal $P_{\text{rx, pri}}$ and the estimation of the path loss between the secondary terminal and the primary terminal L_{path}. This location error increases the $P_{\text{rx, pri}}$ and L_{path} and giving harmful interference to the primary receiver. These two values are varied in a different manner according to the error of the location information of the primary terminal, so we should consider both values to correct the secondary transmit power. However, it is difficult to obtain the worst case location of the primary terminal by considering both values, because the estimation of the worst interference requires large complexity. In this paper, we consider $P_{\text{rx, pri}}$ and L_{path} separately.

The allowable interference I_{allow} can be calculated by using the estimated $P_{\text{rx, pri}}$. When the estimated $P_{\text{rx, pri}}$ is larger than the true value due to the location error, the estimation error has the possibility which does not enable the secondary terminal to avoid interference. This problem occurs when the distance between the primary BS and the primary terminal decreases. Therefore, we assume that the location of the primary terminal is farthest from the primary BS in the error circle. Additionally, when the distance between the primary terminal and the secondary terminal increases due to their location error, the estimated L_{path} is larger than the true value. As a result, the secondary terminal determines the transmit power considering the excess path loss, and the interference power is lager than the allowable interference of the proposed criterion. In order to solve this problem, we assume that the location of the primary terminal is nearest from the secondary terminal in the error circle.

The positional relationship of two modified locations and terminals is shown in Fig. 2. Here, case 1 is the modified location about $P_{\text{rx, pri}}$ and case 2 is that about L_{path}. We calculate $P_{\text{rx, pri}}$ and L_{path} to keep the primary protection separately with considering the location error to reduce the computational cost.

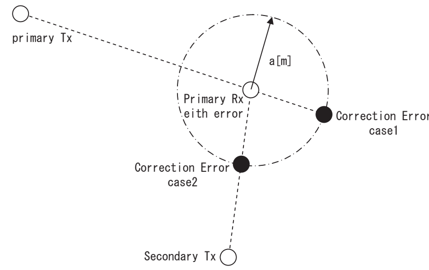

Fig. 2. Modification location of primary terminal.

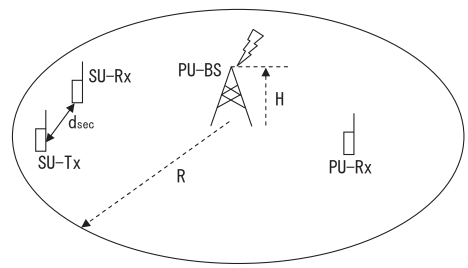

Fig. 3. System model.

V. Computer simulation

As mentioned above, we propose a spectrum sharing criterion based on CCR, a power control method based on CCR and a power control method considering location error . In order to evaluate the effectiveness of the proposed methods, we perform the computer simulations.

A. *Simulation environment*

In the simulations, we consider a down link channel of one cell as a primary system using WiMAX [5] parameters that are shown in Fig. 3. We assume the primary system has no intercell interference. A Primary BS, a primary terminal, and a pair of secondary terminals exist in a cell. This model supposes that the secondary receiver may exist out of the edge of the cell if the secondary transmitter is located near the cell edge. The evaluation environment is that the secondary system transmits the signal using the same frequency at the same transmission time of the primary system.

In order to evaluate the CCR improvement, we calculated complementary cumulative distribution function (CCDF) of achievable capacity of the secondary system, and cumulative distribution function (CDF) of CCR. The location of each terminal is randomly decided by uniform ditsirbution, and we obtain the results by changing the spatial distribution from a million trials. Simulation parameters are shown in Table I.

B. *Simulation result of proposed power control*

For evaluating the effectiveness of the proposed methods, we compare the achievable capacity of the proposed method and other two methods with different achieving criterion. The first compared power control is a power control using the fixed small transmit power for protecting the primary

TABLE I
SIMULATION PARAMETERS.

Propagation loss	n	3 (cubic law)
Carrier frequency	f	2.5[GHz]
Noise floor	$N_{\text{pri,dBm}}$	-95.38[dBm]
Radius of primaray cell	R	1400[m]
Transmit power of primary	$P_{\text{tx,pri,dBm}}$	30[dBm]
Antenna height of primary BS	H	32[m]
Allowable minimum CCR	α	0.92
Allowable maximum probability	β	0.01
Communication distance of secondary	d_{sec}	50[m]

system based on the criterion (using fixed power method). The other compared power control is a power control to keep the SIR of the primary receiver above certain value with achieving criterion (keeping SIR method). In the latter method, we suppose that the secondary terminal can obtain external information from the server, and can determine the transmit power considering condition of the primary terminal and path loss. The required parameters (e.g. transmit power or minimum SNR) that maximize the capacity of the secondary system with achieving the proposed criterion based on CCR in these comparing methods are obtained by the simulation. As a result, we determine that the fixed transmit power is 0[dBm] by using the fixed power method, and allowable minimum SNR is 24[dB] for keeping SIR method.

Simulation results are shown in Figs. 4 and 5. Fig. 4 shows the probability that capacity of primary terminal is decreased due to secondary transmission in the simulation for $\alpha = 0.92$ and $\beta = 0.01$. The probability that the capacity of primary terminal is decreased to $\alpha = 0.92$ is achieved below 0.01 in all methods as shown in Fig. 4. Expressly, the performance of the proposed power control method achieves the probability of $\alpha = 0.92$ is zero. Fig. 5 illustrates the CCDF of the capacity of the secondary system with achieving the criterion based on CCR. The probability curve of the fixed transmit power is reduced to be zero around 2.0[bps/Hz]; therefore the maximum achievable capacity by using the fixed transmit power method is about 2.0[bps/Hz]. The keeping SIR method increases the maximum achieving capacity; however its probability is very low. In the proposed power control method based on CCR, the maximum achieving capacity is almost the same as the keeping SIR method and its probability is higher than the other two methods.

The compared two methods requires excess protecting because it is difficult to achieve the criterion based on CCR without power control at the worst case location. The reason can be found in Fig. 4. Since the probability of the primary capacity around below CCR = 0.92 in the two compared methods is non zero, the secondary terminal have to limit the maximum allowable transmit power in the whole area for keeping this probability decreasing to 0.01. On the other hand, the proposed method can achieve the criterion based on CCR without excess protecting the transmit power, thus the achieving capacity is higher than the other methods.

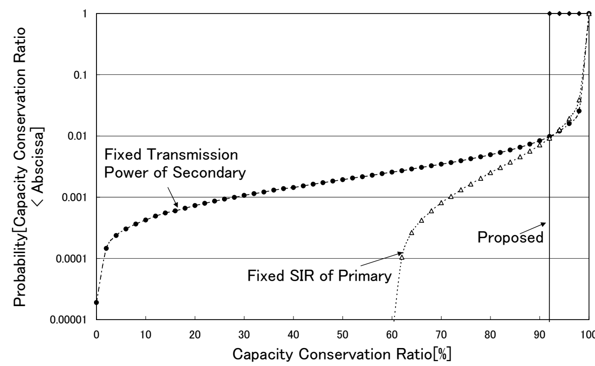

Fig. 4. CDF of primary CCR.

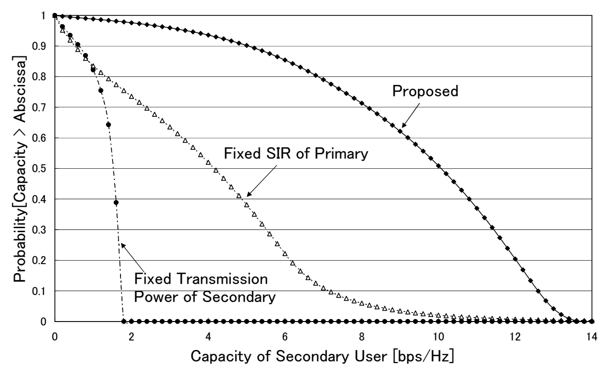

Fig. 5. CCDF of capacity of secondary system with achiving criterion ($\alpha = 0.92$, $\beta = 0.01$).

C. Simulation result of power control considering location error

In order to evaluate the effectiveness of the proposed power control method with considering the location error, we compare the performances with and without proposed power control, location error by deriving the decreased capacity of the secondary system due to considering location error. In the simulation, we assume that the secondary system can obtain the perfect standard deviation σ of error, σ is changed as 10, 30 and 50[m]. As the allowable minimum probability β of miss protecting is 0.01, we set ξ in equation (7) to 0.01. Thus a is calculated as a=30.35, 91.05, 151.74[m] from equation (7).

CDF of the primary CCR with location error and its extended figure are shown in Figs. 6 and 7. If the location information includes error, the secondary system cannot perfectly protect the primary system. As a result, the probability that the capacity of the primary terminal decreases below α becomes non zero. Figures 6 and 7 show that this probability using the power control without considering the location error exceeds $\beta = 0.01$. On the other hand, the proposed method can achieve the criterion.

The protected primary system can be achieved by using the proposed method. Next we evaluate the impacts of the

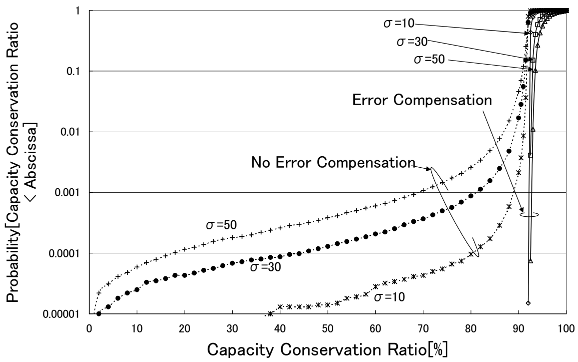

Fig. 6. CDF of primary CCR with error.

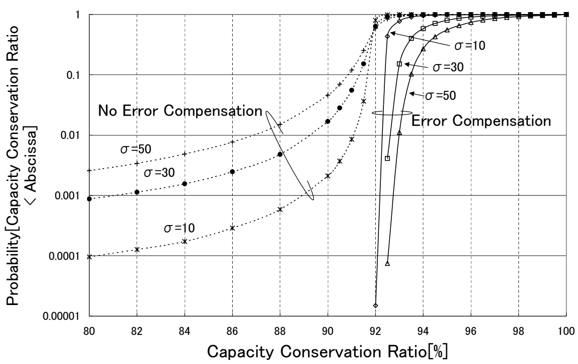

Fig. 7. CDF of primary CCR with error (extended figure).

achievable capacity of the secondary system by applying the proposed method. When the location information has a large error, the secondary system determines the lower transmit power for considering the worst case. Therefore, the transmit power of the secondary transmitter is required to be smaller than the transmit power without location error. Aa a result, the capacity of the secondary system is decreased. CCDF of the secondary system capacity using the proposed power control considering location error is shown in Fig. 8. Fig. 8 shows the probability of the achievable capacity decreases in total as the σ increases.

VI. Conclusion

A spectrum sharing criterion based on the CCR for protecting a primary terminal with various SNR and the power control method based on CCR have been presented. The power control method based on CCR has shown increasing the capacity of the secondary system while avoiding the interference toward the primary terminal with various SNR. However, the proposed method requires the accurate location information for protecting the primary system. Therefore, we also have considered the modified power control method considering location error based on the deviation of error. This method can decrease the probability of miss protection due to the estimated location error.

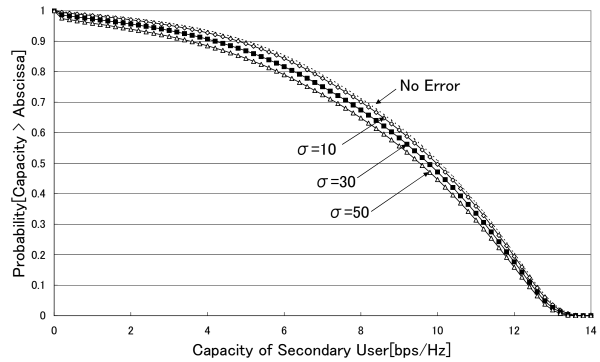

Fig. 8. CCDF of capacity of secondary system with achieving criterion with error.

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