

Distance based an Efficient Transmit Power Control Scheme in Cognitive Radio System with Multiple Antennas

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ABSTRACT

In this paper, a transmit power control scheme for a cognitive radio system (CRS) in a Rayleigh fading channel based on the location information of primary user is proposed. The situation where primary user (PU) i.e. licensed user share the spectrum with secondary user (SU) i.e. cognitive radio have been considered. First a mathematical model for probability of detection as a function of distance between PU transmitter and SU transmitter is developed. The mathematical model takes into account multiple antennas at SUs and uses energy detection (ED) with selective combining (SC) scheme. The maximum allowable transmit power at SU transmitter, to guarantee decodability of PU transmitter signal at PU receiver, is calculated by using the distance between PU transmitter and SU transmitter. The simulation results show that the probability of detection improves with the use of multiple antennas at SU transmitter. This improved probability of detection will result into more accurate calculations of the maximum allowable transmit power at SU transmitter.

Keywords

Cognitive radio (CR), dynamic spectrum access (DSA), energy detection (ED), path loss, probability of detection, transmit power control.

1. INTRODUCTION

Due to efficient utilization of available spectrum resources, cognitive radio (CR) has become an emerging software defined radio (SDR) technology in wireless communication networks. According to Simon Haykin, a cognitive radio can be defined as [1]. "Cognitive radio is an intelligent device that is sensitive of its neighboring environment also known as outside world, and uses the methodology of understanding by building to learn from the environment and adapt its internal states to statistical variations in the incoming RF stimuli by making corresponding changes in certain operating parameters such as transmit power, carrier frequency, and modulation strategy etc. in real-time, while keeping two primary objectives in mind. One is exceedingly trustworthy communications wherever and whenever needed and another one is efficient utilization of the radio spectrum". Due to ever increasing requirement of maximum data rate, throughput and efficiency in most of the latest wireless applications, spectrum assets are facing massive demands. There is limited spectrum available for a particular application, regulated by government agency known as Federal Communications Commission (FCC). Within the current spectrum regulatory structure, many parts of the spectrum are entirely allocated to specific

services and no violation from cognitive users is legitimate. To overcome the conflict between spectrum scarcity and spectrum under-utilization [2], it became strong motivating factor for the researchers to take up their research work in this particular area. Cognitive radio [3] [4], including SDR dynamic spectrum access (DSA) promises to provide a way to promote the spectrum utilization by allowing the unlicensed secondary user (SU) to dynamically access a spectrum hole unoccupied by the primary user (PU) at the right location and right time.

To optimize the spectrum usage and adapt its transmission and reception parameters accordingly without disturbing the quality of service of the primary user, first we have to perform spectrum sensing [5]-[6] which is one of the most vital issues of cognitive radio technology. Based on this sensing information, SUs start transmission once the unoccupied spectrum is found. This opportunistic transmission by SUs will interfere with PUs if the SUs fail to detect the presence of the PUs signal, i.e., misdetection (MD), and starts the transmission in the same frequency band with a transmit power larger than a limit which can be decided based on the noise floor and the interference protection ability of the PUs.

Multiple techniques have been discussed in the literature to overcome the interference at PU by controlling the transmit power level of SU. Flexible spectrum shaping in orthogonal frequency division multiplexing (OFDM) is strongly considered as a suitable candidate for cognitive radio [6] to avoid interference with the licensed user. Beamforming based on the instantaneous channel state information (CSI) [7] from the SU transmitter to the PU receivers allows the SU suppresses the interference to PUs. One more scheme for transmit power level control in CRS is based on spectrum sensing side information (SSI) [8] [9], wherein we first calculate shortest distance between CR and PU receiver; then based on the minimum distance, transmit power can be controlled. In another approach, by employing adaptive power control scheme [10], we allow transmit power adaptation at the SU transmitter to maintain a constant output SNR to the secondary user receiver and limit the interference to a primary user within an interference constraint. In CRS transmit power can also be controlled under cooperative and non-cooperative spectrum sensing [11] to either maximize the average data rate or minimize the outage probability of the SU.

In this paper, we proposed an efficient transmit power control scheme based on location information of PU with multiple antennas at SUs, which allows SU transmitters to aggressively increase the level of their transmit powers while still

guaranteeing an acceptable level of aggregate interference at the PU receivers. In order to estimate allowable transmit power for SU we considered received SNR as a proxy to determine the shortest distance between SU transmitter and PU receiver. We have also derived a mathematical model for calculating shortest distance in terms of probability of detection.

This paper is organized as follows: System model for CRS is given in section 2. Proposed methodology to calculate the shortest distance between PU receiver and SU transmitter is described in Section 3. In section 4, we derived mathematical expression for maximum allowable transmit power of SU as a function of shortest distance calculated in section 3. Then in section 5, simulation results are presented and discussed. Finally, conclusions are drawn in section 6.

2. SYSTEM MODEL

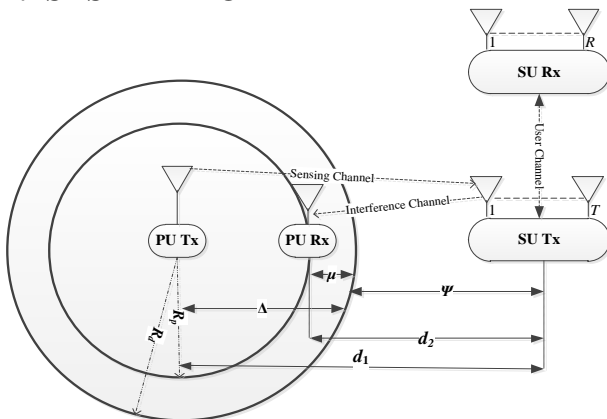


Fig.1. System model for CRS

System model for cognitive radio system is shown in Fig.1, where the primary and secondary users coexist in the same area and using same frequency band. Here primary transmitter and receiver are represented by PU Tx and PU Rx respectively; whereas secondary transmitter and receiver are represented by SU Tx, and SU Rx respectively. In order to get better sensing information we are considering multiple numbers of antennas denoted by T and R at SU Tx and SU Rx respectively. The circles covered with the radius R_d and R_p represents, respectively, the decodable region within which the SNR of decodability occurs in the absence of interference to the PU Rx and the protection region within which the PU Rx must be guaranteed successful reception in the presence of SU. Here we are considering received SNR as a proxy for estimating the shortest distance between PU Rx and SU Tx. So Δ and μ (both measured in dB), respectively, represent path loss in the region corresponding to R_d and how much interference above the noise floor the primary system can tolerate i.e. protection margin. There are three types of channels shown in the system model. The user channel is the channel between SUs, sensing channel is the channel from PU transmitter to SU transmitter and the interference channel is the channel from SU transmitter to PU receiver. Symbols d_1 and d_2 (both measured in meters) represent the distances between PU Tx – SU Tx and between PU Rx – SU Tx respectively.

In our proposed scheme to control the transmitted power level of SU transmitter for a known transmit SNR of PU, distance d_2 is required. Due to lack of awareness about the right location of PU and exact channel information, the calculation of distance d_2 is very difficult. Therefore, as shown in the system model, the path loss between PU Tx and SU Tx

is represented by $(\Delta + \Psi)$ dB. Now, if transmit power of the SU depends on the path loss $(\mu + \Psi)$ dB between PU Rx and SU Tx.; then, the transmit power control problem is essentially converted to the problem of evaluating the path loss due to d_1 for a given μ and Δ . We take the path loss exponent between PU Tx – PU Rx as α_1 and between SU Tx – PU Rx as α_2 , which are usually constant in the range 2 ~ 5.

3. PROPOSED METHODOLOGY TO CALCULATE DISTANCE BETWEEN PU TRANSMITTER AND SU TRANSMITTER

In this section we discuss our proposed methodology to calculate the distance d_1 between PU Tx and SU Tx which will be used to control and determine maximum allowable transmit power at SU Tx while still guaranteeing decodability of PU signal at PU Rx in the protected region.

3.1 Spectrum Sensing

Spectrum sensing is one of the most vital issues of cognitive radio technology as it should be firstly performed before allowing unlicensed users to access an unoccupied licensed band, to ensure the efficient utilization of the spectrum without disturbing the quality of service of the primary user. There are many techniques for spectrum sensing available in literature. Some of them are discussed in [5] [6].

- Energy Detection: The energy detection method is optimal for detecting any unknown zero-mean constellation signals.
- Matched filter: It is an optimal method for detection of signals. Matched filter maximizes the signal to noise ratio of the received signal in the presence of AWGN.
- Cyclostationary Detection: If the signal of the primary system has cyclic characteristics, that signal can be detected at very low signal to noise ratio (SNR) by using a cyclostationary detection technique.

In order to avoid the interference at the PU Rx, the SU should sense the spectrum opportunity. Due to its less complexity in implementation, we use energy detection with selective combining for sensing the available unoccupied frequency band.

If $y(t)$ is the received signal at the SU Tx, $x(t)$ is the transmitted signal from PU Tx, $n(t)$ is the zero-mean additive white Gaussian noise (AWGN) with the variance σ^2 and h denotes the Rayleigh fading channel coefficient. The objective of spectrum sensing is to decide between the following two hypotheses:

When the PU Tx is not active, which is referred to as hypothesis H_0 , the received signal at the i^{th} antenna of SU Tx is given by:

$$y(t) = n(t)$$

When the PU Tx is active, which is referred to as hypothesis H_1 , the signal received from the PU Tx at the i^{th} antenna of SU Tx can be written as:

$$y(t) = \sqrt{G_s} h x(t) + n(t)$$

Where, G_s represent path loss of sensing channel.

Based on these two hypotheses H_0 and H_1 average probability of false alarm, probability of detection and probability of missing over Rayleigh fading channel can be determined respectively as given, [12]

$$P_f = E[\text{prob}\{H_1/H_0\}]$$

$$P_d = E[\text{prob}\{H_1/H_1\}]$$

$$P_m = E[\text{prob}\{H_0/H_1\}] = 1 - P_d$$

Where, E represent expectation operator.

Closed form expression for the detection probability by using the energy detection (ED) with selective combining (SC) in a Rayleigh fading channel [10] is given by,

$$P_{d,SC}(T, N_0) = 2T \sum_{n=0}^{T-1} (-1)^n \binom{T-1}{n} \frac{1}{p^2} \left(\frac{-b^2}{2} \right) \times \left\{ \left(\frac{p^2+a^2}{a^2} \right)^{N_0-1} \right. \\ \left. \left[\exp\left(\frac{1}{2} b^2 \frac{a^2}{p^2+a^2} \right) - \sum_{m=0}^{N_0-2} \frac{1}{m!} \left(\frac{1}{2} b^2 \frac{a^2}{p^2+a^2} \right)^m \right] \right. \\ \left. + \sum_{m=0}^{N_0-2} \frac{1}{m!} \left(\frac{b^2}{2} \right)^m \right\} \quad (1)$$

Where, symbols p , a and b are defined in terms of number of samples (N_0), detection threshold of ED (E_{th}), average sensing SNR (Γ_s) and standard deviation of the receiver noise (σ_z) at SU Tx.

$$p = \sqrt{(n+1)} \quad a = \sqrt{2\Gamma_s N_0} \quad b = \frac{\sqrt{2E_{th}}}{\sigma_z}$$

In order to calculate the detection probability by using equation (1), we require the value of decision threshold E_{th} for a given false alarm rate, P_f . E_{th} can be determined using equation (2) given below in which $\Gamma(\cdot, \cdot)$ and $\Gamma(\cdot)$ denotes incomplete gamma function and gamma function respectively.

$$P_f(E_{th}, N_0, \sigma_z) = \Gamma(N_0, E_{th} / 2\sigma_z^2) / \Gamma(N_0) \quad (2)$$

3.2 Relation Establishment between SNR and Distance

To calculate distance d_2 for controlling the transmit power of SU is very difficult because we do not know the exact location of PU as well as exact channel state information. As mentioned in our system model, discussed in section 2, the problem of finding d_2 , is essentially the problem of finding d_1 . The distance, d_1 , can be estimated by measuring the local SNR of the PU Tx at SU Tx with the help of pilot signal as well as sensing SNR. In this sub-section, we have derived the relationship between sensing SNR and distance (d_1). The path loss due to distance d_1 between PU Tx and SU Tx is given by,

$$\eta \square -10 \log \left(d_1^{(-\alpha_1)} \right), dB \quad (3)$$

In term of average sensing SNR (Γ_s) and transmit SNR of PU Tx (Γ_t) above equation can be written as,

$$= 10 \log(\Gamma_t) - 10 \log(\Gamma_s) \quad (4)$$

From equation (3) and (4) average SNR of sensing channel can be represented in term of transmit SNR of PU Tx and distance d_1 as

$$\Gamma_s = \Gamma_t d_1^{(-\alpha_1)} \quad (5)$$

3.3 Distance between PU Tx and SU Tx

Now substitute equation (5) in equation (1) we get detection probability as a function of distance d_1 .

$$P_{d,SC}(T, N_0) = 2T \sum_{n=0}^{T-1} (-1)^n \binom{T-1}{n} \frac{1}{p^2} \left(\frac{-b^2}{2} \right) \times \\ \left\{ \frac{p^2+2\left(\Gamma_t d_1^{(-\alpha_1)}\right)^{N_0}}{2\Gamma_s N_0} \right\}^{N_0-1} \left[\exp\left(\frac{1}{2} b^2 \frac{2\left(\Gamma_t d_1^{(-\alpha_1)}\right)^{N_0}}{p^2+2\left(\Gamma_t d_1^{(-\alpha_1)}\right)^{N_0}} \right) \right. \\ \left. - \sum_{m=0}^{N_0-2} \frac{1}{m!} \left(\frac{1}{2} b^2 \frac{2\left(\Gamma_t d_1^{(-\alpha_1)}\right)^{N_0}}{p^2+2\left(\Gamma_t d_1^{(-\alpha_1)}\right)^{N_0}} \right)^m \right] + \sum_{m=0}^{N_0-2} \frac{1}{m!} \left(\frac{b^2}{2} \right)^m \right\} \quad (6)$$

$$P_{d,SC}(T, N_0) \square f(d_1) \quad (7(a))$$

$$P_m = 1 - P_{d,SC}(T, N_0) \square 1 - f(d_1) \quad (7(b))$$

By using the above equation (7(a)), we can calculate distance d_1 between PU Tx and SU Tx for any particular value of detection probability, $P_{d,SC}$.

4. PROPOSED TRANSMIT POWER CONTROL SCHEME AS A FUNCTION OF DISTANCE d_1

In this section, we derived mathematical expression to determine the maximum allowable transmit power at SU Tx while still guaranteeing decodability of PU signal at PU Rx in protected region.

Let P_p and P_s are the transmit powers of primary and secondary transmitters, respectively, with their corresponding received powers at PU Rx denoted by P'_p and P'_s , on the edge of the protected region. If noise power at PU Rx denoted by σ_w^2 , then guaranteed decodability of PUTx signal at PU Rx having decodable SNR (Γ_{dec}) can be expressed as:

$$10 \log \left(\frac{P'_p}{P'_s + \sigma_w^2} \right) \geq \Gamma_{dec}$$

$$\frac{P'_p}{P'_s + \sigma_w^2} \geq 10^{\Gamma_{dec}/10}$$

$$P'_s \leq \sigma_w^2 (10^{\mu/10} - 1) \quad (8)$$

In order to successful reception of PU Tx signals at PU Rx, a fundamental constraint for any cognitive system is given by above equation (8).

The allowable maximum transmit power for secondary user in terms of distance d_2 between PU Rx and SU Tx, thus, can be expressed as:

$$P_s \leq d_2^{\alpha_2} \sigma_w^2 (10^{\mu/10} - 1) \quad (9)$$

Now, by using received SNR as a proxy for calculating the value of distance d_2 , transmit power of secondary transmitter can be controlled by using equation given below [13]

$$10 \log \left(\frac{P_s}{\sigma_w^2} \right) \leq \frac{\alpha_2}{\alpha_1} \Delta + 10 \log (10^{\mu/10} - 1) + 10 \alpha_2 \log \left\{ \left(10^{\mu/10} \right)^{1/\alpha_1} - \left(10^{-\mu/10} \right)^{1/\alpha_1} \right\} \quad (10)$$

The first term describes, that how far a PU Rx can travel from the PU Tx and still decode the signal. The second term represents how tolerant the protected primary receivers are to interference. The final term represents how far the secondary transmitter is from the protected receivers.

$$P_s^{\max} |_{dB} \leq \frac{\alpha_2}{\alpha_1} \Delta + 10 \alpha_2 \log \left\{ \left(10^{\mu/10} \right)^{1/\alpha_1} - \left(10^{-\mu/10} \right)^{1/\alpha_1} \right\} + 10 \log (10^{\mu/10} - 1) + 10 \log (\sigma_w^2) \quad (11)$$

$$P_s^{\max} |_{dB} \square g(\psi) \quad (12)$$

$$\square g(\eta - \Delta)$$

$$P_s^{\max} |_{dB} \square g \left(-10 \log \left(d_1^{-\alpha_1} \right) - \Delta \right) \quad (13)$$

Where, P_s^{\max} denotes the maximum value of transmit power used at SU transmitter and, as shown above in equation (13), this maximum allowable transmit power at SU Tx is controlled on the basis of calculated distance d_1 between PU Tx and SU Tx.

5. SIMULATION RESULTS

In sections 3 and 4, we have developed the mathematical models to determine the maximum allowable transmit power at SU Tx while still guaranteeing decodability of PU signal at PU Rx in the protected region. In this section, we present and discuss the simulation results of the proposed transmit power control scheme. The simulations have been carried out in MATLAB. For simulation purpose, the parameters as shown in table 1 have been considered.

Table 1. Simulation Parameters

S. No.	Name of the parameter	Value
1	Path loss in the region corresponding to R_d	$\Delta = 100$ dB
2	Protection margin.	$\mu = 1$ dB
3	Transmit SNR of PU	$\Gamma_t = 100$ dB
4	False alarm rate	$P_f = 0.01$
5	Number of Samples	$N_0 = 5$

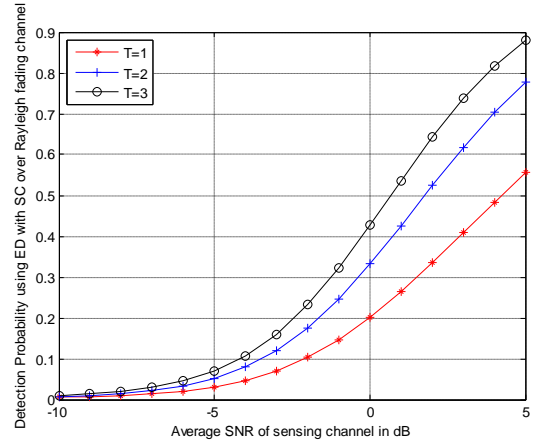


Fig.2. Detection probability using ED with SC in a Rayleigh fading channel. ($P_f = 0.01$ and $N_0 = 5$)

Fig. 3 presents the probability of missing as a function of path loss due to distance for different values of path loss exponent α_1 , for the case of a single antenna at SU Tx. It is seen that the probability of missing increases with increased path loss due to distance between PU Tx and SU Tx. Also, for a particular path loss, a larger path loss exponent will result into increased probability of missing. This is because of the fact that larger the path loss exponent; worse is the wireless communication environment.

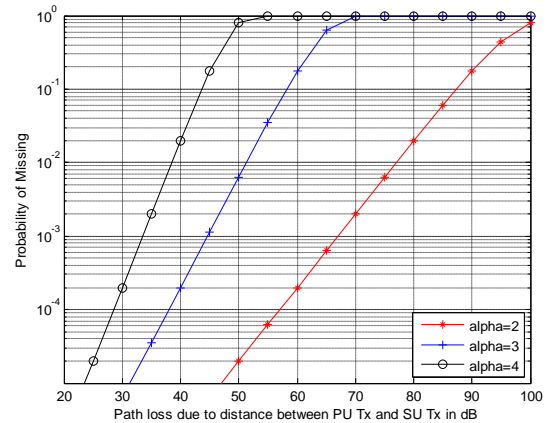


Fig.3. Probability of missing (P_m) versus path loss due to distance (d_1) for different value of path loss exponent between PU Tx and SU Tx.

In fig. 4, we have plotted the probability of missing as a function of path loss due to distance, for different number of antennas at SU Tx, while keeping path loss exponent $\alpha_1 = 2$. Result shows that when cognitive radio is experiencing heavy path loss from the PU Tx, the probability of missing is increased. Also, as is evident, for a particular path loss, the probability of missing can be reduced by employing more number of antennas at SU Tx.

As shown in Fig. 5, the allowable transmit power of the SU transmitter can be increased when a heavy SNR loss occurs between the secondary transmitter and the primary receiver. This is reasonable because the interference power that the cognitive radio inflicts on the primary receiver is reduced by the large path loss.

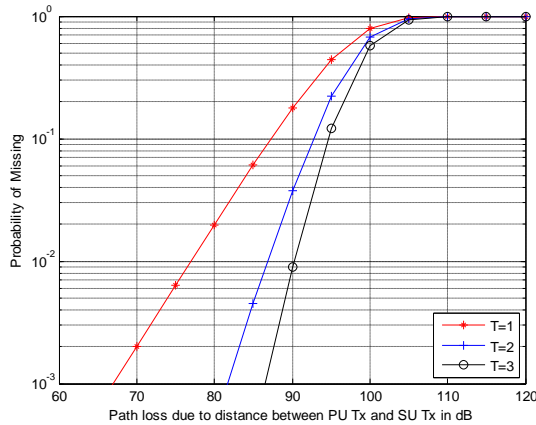


Fig.4. Probability of missing (P_m) versus path loss due to distance (d_l).

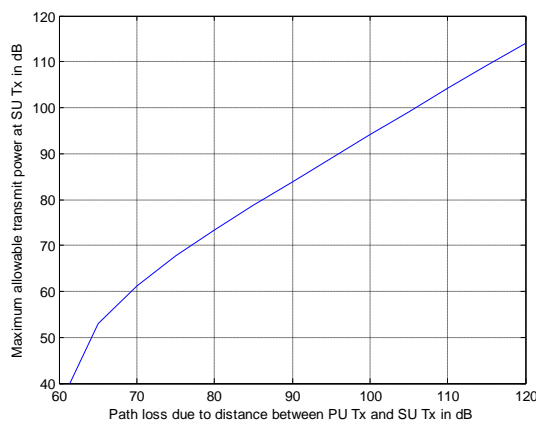


Fig.5. Maximum secondary transmitter power (P_s^{\max}) versus path loss due to distance (d_l).

Finally, Fig. 6 combines the results obtained in fig.4 and fig. 5. It demonstrates the relationship between maximum allowable transmit power P_s^{\max} and probability of missing P_m for different number of antenna at SU Tx.

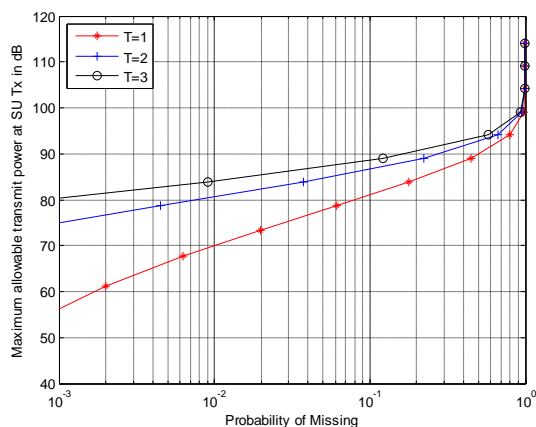


Fig.6. Maximum secondary transmitter power (P_s^{\max}) versus Probability of missing (P_m).

This figure also emphasizes the fact that higher probability of detection can be achieved by employing more number of

antennas at SU Tx. It is also obvious that better the probability of detection, more accurate will be our power control scheme.

6. CONCLUSION

In this paper, we considered the situation where primary user (PU) shares spectrum with secondary user (SU) i.e. cognitive radio. We have proposed a distance based efficient transmit power control scheme which calculate maximum allowable transmit power at SU transmitter while guarantying decodable signal of PU transmitter at PU receiver in presence of cognitive radio. In order to calculate desired distance we have also derived a mathematical model for probability of detection in terms of distance between PU transmitter and SU transmitter which includes the location information of primary user indirectly. This scheme has shown that we can achieve better sensing performance by employing more number of antennas at SU Tx. Because of better sensing performance, we can exercise more accurate control on transmit power of SU Tx. In this work, though, we considered worst case scenario where PU Rx is at shortest distance to SU Tx; however, the proposed scheme is equally applicable to maintain a quality-of-service for the PU by limiting the interference generated by SU Tx, at any location.

7. ACKNOWLEDGEMENT

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