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PA Nonlinearity and Power Allocation in CRN

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Abstract: ***In the resource allocation of the cognitive radio network the interference to the primary receiver is a critical issue. For instance the power amplifier nonlinearity causes nonlinear interference to the primary receivers. Consider the nonlinear effects of the power amplifier on the received SNR at the secondary receiver and the adjacent channel interference at the PR. To calculate the throughput an analytical expression is derived for the probability of data transmission between the secondary users and the primary receivers. Performance and analysis are based on the both the peak and average power constraints. Through knowledge about theoretical analysis and simulation results, maximum achievable average SNR is calculated.***

Keywords: Cognitive radio, power control, power amplifier, adjacent channel interference, dual decomposition

1. Introduction

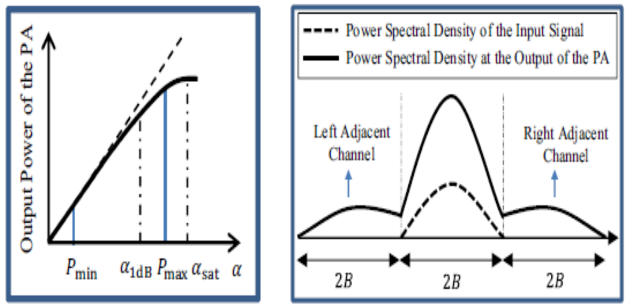
Cognitive radio is a transceiver system, it is a form of wireless communication, in which transceiver can intelligently detect which communication channel is in use and which is not in use and currently move into the vacant channel while avoiding occupied one. The functions of cognitive radio are, power control, spectrum sensing, wide band spectrum sensing and spectrum management. CR is also a promising technology for the future radio spectrum management. In CR networks interference temperature limit is explained as the secondary users are allowed to communicate, the interference to the primary receiver are below the given threshold level.

The crucial element in the wireless transmitters are the power amplifiers (PA), during transmission which consumes large portion of energy. When the power amplifier is driven towards saturation the, nonlinear distortion increases. The highest efficiency is obtained at the saturation point. The nonlinear characteristics of the power amplifier causes spectral regrowth of its signal, as a result adjacent channel interference is occurred. By considering the interference temperature limit, the nonlinear behavior of the PA and its resulting adjacent channel interference in the cognitive radio network. To find the power constraint and achieve the goal best strategy is considered.

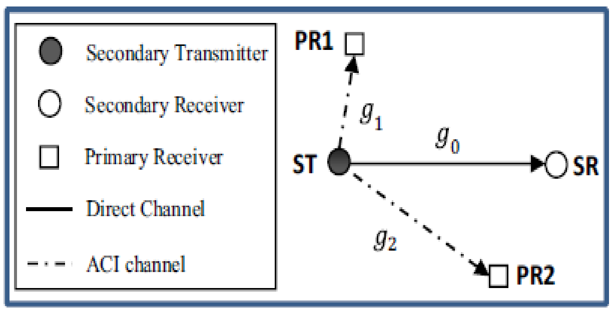
Average bit error rate can be minimized by the optimal power allocation strategy using average and peak power constraints. Assume the linear power amplifier bahavior only short term interference is considered and also fading effects are not considered. In the sleep mode there is no data transmission occurs in the radio frequency range. To find the nonlinear effects of power amplifier on the received signal-to- noise ratio at the SR and throughput also considered. The throughput of the secondary system is derived as a function of the data signal statistics.

2. System Model

The model of the data signal at the secondary transmitter (ST),nonlinear power amplifier at the secondary transmitter and its adjacent channel interference are explained in the system model. In the receiver the received signal at the secondary receiver(SR) and the interference to the PR are considered.



(a) (b)



(c)

Figure 1(a): output power of a nonlinear PA as a function of the input power scale, (b) power spectral density of the input and output signal of a PA , (c) secondary transmitter and receiver with the left and right ACI to the PR1 and PR2.

2.1 Input Signal and Nonlinear PA Model

Let us assume that the baseband equivalent of the signal of the PA at the secondary transmitter as follows in the equation below

$$x(t) == \sqrt{\alpha}\sum_{-\infty}^{+\infty} s_n h(t-nT) \quad (1)$$

whereα is the power scaling factor,S_n is the n[th] data symbol, and T is the data symbol period. Unit energy band shaping filter is h(t), H(f) is zero for f>B. Before transmitting in to the channel, the input signal has to be amplified. Fig 1.(a) shows the output power of the nonlinear PA as a function of the input power scale factor, α. When increasing the input power of the PA, the output power cannot increase linearly and it move towards saturation.

2.2 Received Signals

The signals are transmitted from the secondary transmitter (ST) to the secondary receiver (SR) in the central band shown in the Fig .1(b) ,while the nonlinear PA in the secondary transmitter causes interferences to the adjacent channels. Assume the block fading channels the channel gains are iid (independent and identically distributed).From Fig.1(c) the signals are transmitted from the secondary transmitter to the secondary receiver and is given by

$$y(t) = \sqrt{g_0} e^{j\theta_0} z(t) + n(t) \quad (2)$$

where n(t) is acomplex valued zero mean white guassian noise process. A matched filter in the ST is used to recover the data symbol. The average power of the data symbol as follows

$$P_d(\propto) = D1 \propto + D2 \propto^2 + D3 \propto^3 \quad (3)$$

Due to the saturation property of the PA, D1and D2 are positive and D2 < 0, therefore the fading channel gains are considered. g1 is the fading channel gain between ST and the PR1 and g2 is the fading channel gain between ST and the PR2.

3. Two power allocation method for the ST

To maximize the average received SNR at the SR and todetermine the input power scale of theST .From the Fig.1(a) an upper limit and lower limit is considered, upper limit is set for Pmax and lower limit is set for Pmin.

3.1 Power Allocation With PeakACI Constraints

The main objective is to maximize the average received SNR at the SR, which subject to the range of the ST power amplifier and the peak adjacent channel interference to the PRs, is as follows

$$Max_{\propto(v)}. Ev\{SNR(\propto(v)\} \quad (4)$$

$$\begin{cases} \propto(v) = 0 \; PA \; is \; off \\ or \\ Pmin \leq \propto(v) \leq Pmax. \; PA \; is \; on \end{cases} \quad (5)$$

$$g1 P_{AC}(\propto(v)) \leq Q_{peak,1} \quad (6)$$

$$g2 P_{AC}(\propto(v)) \leq Q_{peak,2} \quad (7)$$

The constraint (5) is related to the power amplifier.(6) and (7) related to control the interference from the left and right adjacent channels of the nonlinear PA,PR1 and PR2 are the adjacent channels.when the power amplifier is on, the interference channel gain is very large and Pmin may result in larger interference than the threshold and the PA is switch off.

3.2 Power Allocation With Peak ACI Constraints

From Fig 1(c) the main objective is to maximize the average received SNR at the SR, which subject to the range of the ST power amplifier and the peak adjacent channel interference to the PRs, is as follows

$$\underset{\propto(v)}{Max} \; Ev\left\{\frac{2g_0}{N_0} Pd(\propto(v))\right\} \quad (8)$$

$$\propto(v) € \{0 \cup [P_{min}, P_{max}]\} \quad (9)$$

$$Ev\{\mu g1 \propto^3(v)\} \leq Q_{avg,1} \quad (10)$$

$$Ev\{\mu g2 \propto^3(v)\} \leq Q_{avg,2} \quad (11)$$

The optimization problem can be solved by using the lagrange method. $\propto(v)$is used to maximize the objective function in the peak power constraints.

4. Maximum Achievable Average SNR And Probability of Data Transmission

The power allocation method is used in the ST for allocating the fading blocks,when the power amplifier is on,the maximum achievable average SNR at the fading block can be calculated as

$$SNR_{ach} \triangleq Ev\left\{\frac{2g0}{N0} P_d(\hat{\propto}(v)) \middle| \hat{\propto}(v) € [P_{min}, P_{max}]\right\} \quad (12)$$

Using the conditional expectation policies,$P_d(0) = 0$ the equation becomes

$$SNR_{ach} = \frac{1}{\rho} Ev\left\{\frac{2g0}{N0} P_d(\hat{\propto}(v))\right\} \quad (13)$$

whereρ is the probability of transmission

$$\rho \triangleq \Pr(\hat{\propto}(v) \in [p_{min}, p_{max}]) = 1 - p_r(\hat{\propto}(v) = 0 \quad (14)$$

The value of ρ lies between 0<ρ<1 ,from (13) $SNR_{ach}$is greater than or equal to the average SNR and the power amplifier transmit in the transmit mode, the value of ρ is equal to 1.

4.1 Peak ACI Power Constraint Mode

The channel gains are independent so the probability of data transmission is denoted by ρ_{peak}, is given by

$$\rho_{peak} = 1 + \exp\left\{-\frac{1}{2 p_{min}^3}\left(\frac{Q_{peak,1}}{\sigma_1^2} + \frac{Q_{peak,2}}{\sigma_2^2}\right)\right\} - exp\left\{-\frac{Q_{peak,1}}{2\sigma_1^2 p_{min}^3}\right\} - exp\left\{-\frac{Q_{peak,2}}{2\sigma_2^2 p_{min}^3}\right\} \quad (15)$$

When the interference temperature limit are large ,the upper bound of the SNR_{ach} is shown in equation (12), we obtain an upper bound as follows

$$\frac{2E\{g_0\}}{N_0}\{D_1 P_{max} + D_2 P_{max}^2 + D_3 P_{max}^3\} \quad (16)$$

Similarlly the lower bound can be calculated using p_{min}.

4.2 Average ACI Power Constraint Mode

In average power constraint mode the probability of data transmission can be denoted as ρ_{avg}.the interference temperature limits are very large so to find the bound using the average constraints.

$$\frac{2E\{\{g_0 | \bar{g} < u\}\}}{N_0}\{D_1 P_{max} + D_2 P_{max}^2 + D_3 P_{max}^3\} (17)$$

The power amplifier mostly transmit with maximum power and finaly get the equation.when the interference temperature limit are very small we get the lower bound of the SNRach as follows

$$\frac{2E\{\{g_0|\bar{g} < u\}\}}{N_0}\{D_1 P_{min} + D_2 P_{min}^2 + D_3 P_{min}^3\}(18)$$

5. Simulation Results

The proposed system can be analysed through simulation. In Fig 2 the power allocation with peak ACI constraints and the probability of data transmission in the CR network.as the interference temperature limit increases the probability of data transmission also increases, the value of ρ_{peak} is approaching to 1.

In Fig 3 the maximum average SNR and the achievable average SNR is ploted in the case of peak ACI constraints, so to found the upper and lower limit using these constraints, The SNRacheivable is best at the expense of throughput. In Fig 4 the power allocation with average ACI constraints and the probability of data transmission, for the smaller values of the interference temperature limit,ρ_{avg} is greater than the ρ_{peak} .

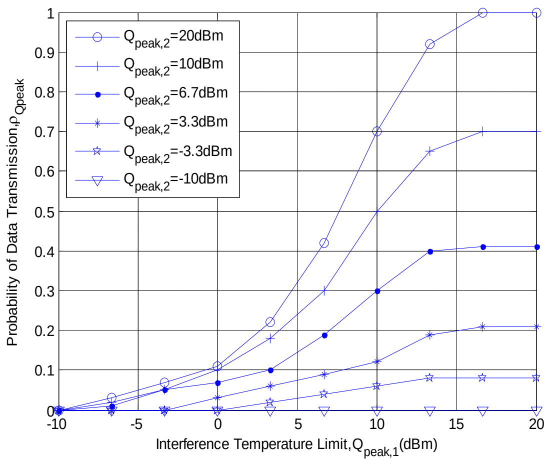


Figure 2: power allocation with peak ACI constraint in terms of interference temperature limit and probability of data transmission.

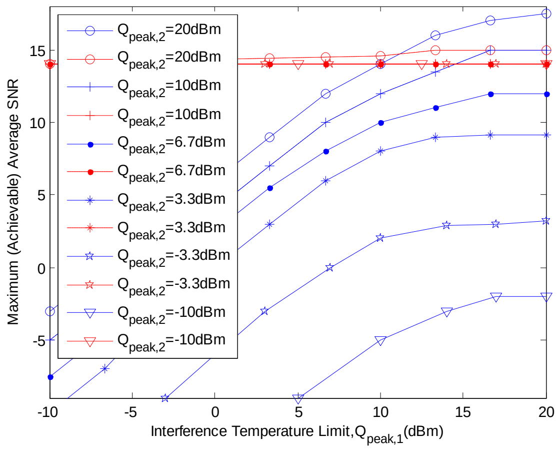


Figure 3: maximum achieved SNR in peak ACI mode

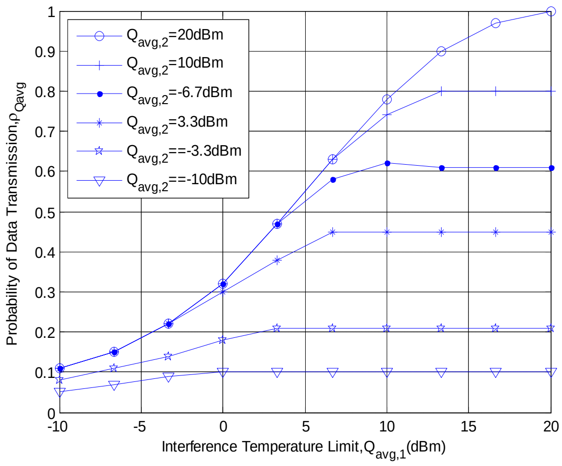


Figure 4: power allocation with average ACI constraint in terms of interference temperature limit and probability of data transmission.

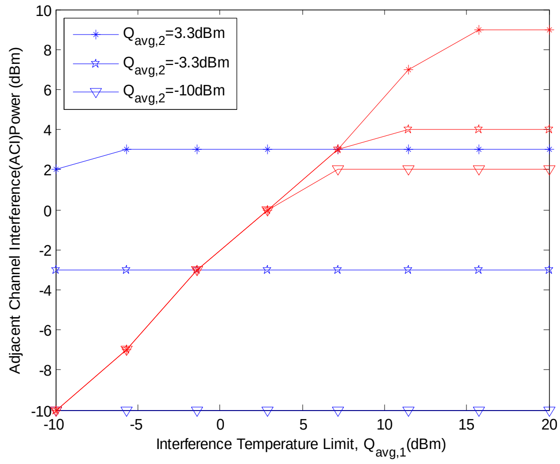


Figure 5: Power receiving from PR1 and PR2 in ACI constraint mode.

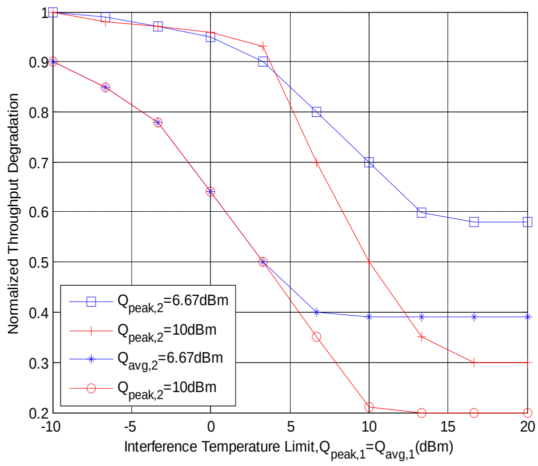


Figure 6: Comparison of normalized throughput degradation in average and peak power constraints

In fig 5 is explained with the help of example,consider the two curves marked with the triangle and the ACI power is fixed at the -10dbm, as the interfence temperature limit increases, ACI power also increases up to a point and the value becomes constant at 2.25dBm. In fig 6 the graph is plotted with interference temperature limit and the throughput,as the limit increases the throughput decreases and highest throughput degradation occurs at the average ACI power constraint mode.

6. Conclusion

In this paper proposed a nonlinear power amplifier and its effect in the cognitive radio network, investigate the peak and average power constraint modes . we derive the analytical expression for the power constraints and the upper and lower limit on the maximum achievable average SNR . Through simulation result average ACI power constraint has less throughput degradation than the peak power constraints and attain maximum achievable average SNR.

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