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Resource Allocation in Cognitive Radio Network using Dirty Paper Coding

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ABSTRACT

Here performance of different cognitive systems are analyzed in different environments and scenarios. The main scenarios are: one cognitive and one primary user, multiple cognitive users and channels and multiple cognitive and primary users. In all scenarios involving one or more primary users, the performance is evaluated over two phases. In Phase 1 the channel is idle, i.e. the primary users are silent, and in Phase 2 the primary users are active on the channel. One of the questions is how can cognitive users transmit simultaneously with the primary user in Phase 2. Schemes that show that this is possible is presented and evaluated and performance is compared to a standard cognitive system only transmitting when the channel is idle. In scenarios with multiple cognitive users and channels, Dirty paper coding Schemes is reviewed. All implementation and simulations were done in MATLAB.

Keywords

Cognitive Radio, Resource Allocation , Dirty paper coding , Tomlinson-Hiroshima Precoding

1. INTRODUCTION

Cognitive radio systems are radios with the ability to exploit their environment to increase spectral efficiency and capacity. As spectral resources become more limited the FCC[1] has recommended that significantly greater spectral efficiency could be realized by deploying wireless devices that can coexist with primary users, generating minimal interference while somehow taking advantage of the available resources [2]. Such devices, known as cognitive radios, would have the ability to sense their communication environment and adapt the parameters of their communication scheme to maximize rate, while minimizing the interference to the primary users. Thus the two most popular research areas when it comes to cognitive radios are spectrum sensing and interference management and resource allocation. Spectrum sensing is the ability to find available frequencies/Timeslots to transmit in. The problem is then that the algorithms need to have as little delay as possible so that once channels are available one can transmit immediately. And of course one would want as few false detections and false no-detections as possible. Research in the area of interference management and resource allocation consists of how to allocate power in channels to maximize capacity while minimizing interference to other users. One way is of course to transmit when no one else is using that frequency/timeslot, but given a scenario where there are multiple cognitive users in the same environment this may not be possible and certainly not the way to maximize capacity. When many users transmit at the same frequency, maximizing capacity for one or all users becomes the problem of optimizing power allocation in an interference channel. Even though this problem was considered as early as 1975 [3] and certain solutions have been obtained in a few cases, the general solution to the problem has not been found to date.

2. DIRTY PAPER CODING

For maximizing the achievable rate for a cognitive user costa's dirty paper coding is used . Creating capacity achieving codes is in itself almost impossible and the codes that are closest to achieve capacity today are turbo codes, if Joint-Source Channel Coding is not considered. Turbo codes, or other high performing codes, are very complex . One way to implement dirty paper coding is a coding technique known as Tomlinson-Hiroshima Precoding (THP) [4]. This was originally designed to remove the effect of inter-symbol interference, but has recently been investigated for broadcast channels to combat interference [5]. The basic concept of THP is shown in Figure 1. The intended signal is denoted U and the interfering signal is denoted S. Since S is known at the transmitter, in order to convey the intended signal U, the transmitter may send U' = U - S to compensate for the interference of S. However, if Mod S is large, the power to transmit U' may violate the power constraint. Given that U is in a finite interval, the power to transmit U' is constrained by applying the modulo operation to U' and transmitting X, the output of the modulo operation. Thus, setting X = U' mod Δ, X is uniformly distributed $\in \left[-\frac{\Delta}{2}, \frac{\Delta}{2}\right]$ if S is Gaussian with large enough power. As a consequence of the modulo operator all symbols that differ by an integer multiple of Δ are considered to be the same symbol. To reconstruct the originally intended signal U, the same modulo operation is done at the receiver.

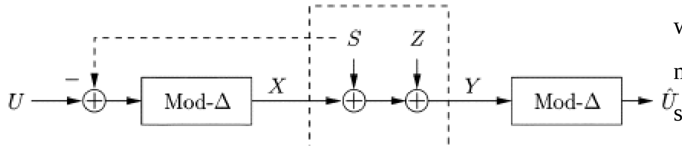

Figure 1 . Principle of THP. U is the intended message, S is the known interference and X is the symbol transmitted on the channel. Z is additive, white, Gaussian noise, Y is the received symbol and $\hat{U}$ is the reconstructed message [5]

The goal of the original paper [6] and the goal of THP are to minimize the effect of interference to maximize the rate over the channel. However, in this setting the effect of the coding on the performance of another system was not considered. To review the effect of using THP, the genie-aided cognitive system was implemented with a cognitive sender transmitting M-PAM signals. For simplicity the primary sender also used M-PAM signaling. Further it is assumed that U, the intended signal at the cognitive sender, is equiprobable. Note that since both the primary message and cognitive message is M-PAM signals, X as described above will not be uniformly distributed between $[-\frac{\Delta}{2} \;, \frac{\Delta}{2}]$ and hence the average power constraint will not be met. To achieve this distribution a dither variable that has a uniform PDF is introduced without any consequence for performance. This variable has to be known both at the sender and receiver . As mentioned above, TH precoding has to be modiffied to limit the effect of interference at the primary receiver. The transmitted signal $X_C = \widetilde{X_C} \; + \sqrt{\alpha P_C/P_P}\, X_P$, $\widetilde{X_C}$ is the intended signal from the cognitive sender and is precoded as described above with $(b + \sqrt{\frac{\alpha P_C}{P_P}}) \, X_P^n$ as the known interference. Given that the average power constraint at the cognitive sender is P_C and remembering that $\widetilde{X_C}$ And X_P are independent,

we get:

$$P_C = E\;[X_C^2\,] = E\;[\;(\widetilde{X_C} + \sqrt{\alpha P_C/P_P}\, X_P)\hat{}2\;]$$

$$= E[\widetilde{X_C^2}] + \frac{\alpha P_C}{P_P} E[X_P^2]$$

$$= E[\widetilde{X_C^2}] + \frac{\alpha P_C}{P_P} P_P$$

$$E\;[X_C^2\,] = (1-\alpha)\; P_C$$

The signal output from the TH precoder $\widetilde{X_C^2}$, is uniformly distributed between $[-\frac{\Delta}{2} \;, \frac{\Delta}{2}]$ The average power is then

$$E[\widetilde{X_C^2}] = \int_{\frac{\Delta}{2}}^{\frac{\Delta}{2}} \frac{1}{\Delta}\; X^2 \,\mathrm{dx}$$

$$= \frac{1}{\Delta} \left[\, 2\,\frac{X^3}{3}\,\right]_0^{\frac{\Delta}{2}}$$

$$= \frac{\Delta^2}{12}$$

Here $\Delta = \sqrt{12(1-\alpha)P_C}$ As mentioned above, all symbols that differ by an integer multiple of Δ will be regarded as the same symbol. Therefore all intended symbols must be within $[-\frac{\Delta}{2} \;, \frac{\Delta}{2}]$ to achieve distinguish ability. Then, to minimize the effect of noise, the distance between each symbol should be maximized, and is given by $\frac{\Delta}{M}$. The M-PAM constellation is then given by

$$[\frac{-(M+1)\Delta}{2M} \,, \frac{-(M+3)\Delta}{2M} \,, \ldots \ldots \; \frac{(M-3)\Delta}{2M} \,, \frac{(M-1)\Delta}{2M}\,]$$

3. SIMULATIONS AND RESULTS

Figure 4. shows again 2-PAM rates with and without THP. In addition the rate of a primary user using 2-PAM and fixed power at 10 dB in a channel with interference from the cognitive user using THP is plotted. The channel

is that given in Figure 2.

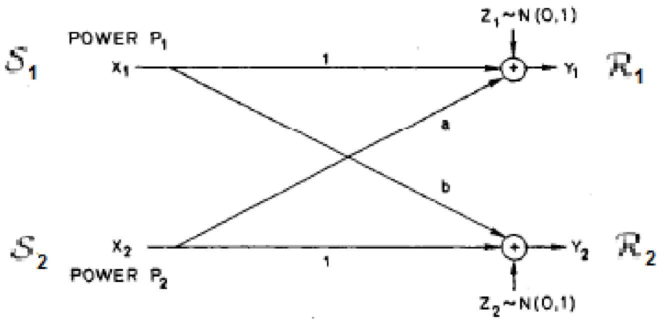

Figure 2 . Standard Gaussian interference channel [8]

with a = b = 0:5. With increasing power at the cognitive user it is clear that the performance of the primary user decreases since the interference increases, whereas the cognitive user only suffers from the power loss of using THP.

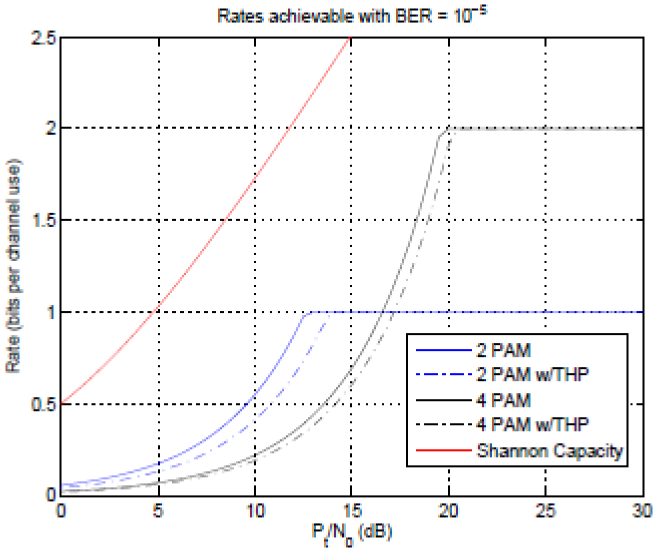

Figure 3. Rate of M-PAM signaling with and without THP. Shannon capacity as reference.

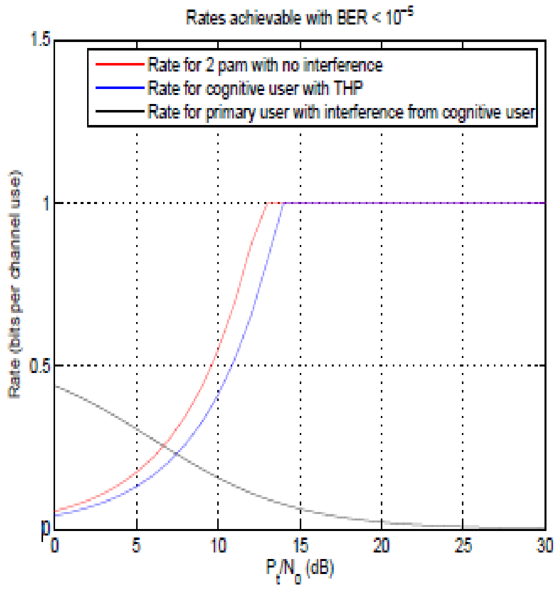

Figure 4 . Rate of 2 PAM signaling with THP, but no interference cancellation

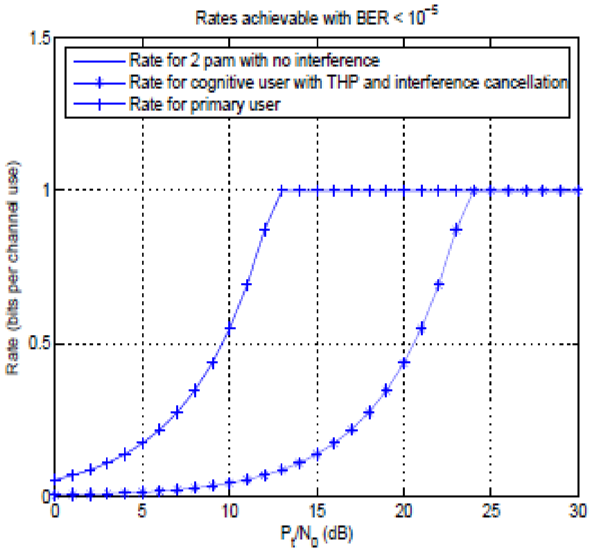

Figure 5. Rate of 2 PAM signaling with THP and interference cancellation.

In Figure 5. performance in the same scenario as in Figure 4. is plotted. The difference is that the cognitive user is now employing THP with interference cancellation so that its signaling does not affect the primary user. As can be seen, the primary user now performs as if the cognitive user was absent all together, whereas the cognitive user suffers from an additional power loss due to the interference cancellation. This power loss depends on α which depends on the channel parameters, transmit power at the primary user and transmit power at the cognitive user. In this plot the channel is that of Figure 2. with a = b = 0:5 and the primary user transmitted at 12.6 dB which is the necessary power to transmit at BER = 10^{-5} with 2-PAM and no interference

4. CONCLUSION

The simulation results show that THP can be used to achieve simultaneous signaling between a primary and cognitive user, although at a severe power penalty at the cognitive sender. In [6] modified trellis codes and convolution codes have been shown to decrease the power loss compared to THP, which is due to the modulo operation and shaping loss of the M-PAM constellation. But the fact that the cognitive user has to limit its interference on the primary user and thus use a portion _ of its power to transmit the primary message is the main cause of the power penalty. In the simulations, a primary user using only M-PAM signaling was considered. Using the same TH precoding for a primary user using any other modulation scheme, such as FSK or QAM, would in essence be the same, because when the cognitive user uses a portion α of its power to transmit the primary signal, it ensures that the primary user exhibits no degradation in performance. However, the TH precoding would have be modiffied so that the cognitive user does not experience any interference from the primary user. This simpliffies if the two uses the same modulation technique.

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