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Power Control in Cognitive Radio

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Abstract*— *Future wireless networks are envisioned to utilize new paradigms of spectrum reuse, i.e. cognitive radio. where radio frequencies can opportunistically be taken into use if no other use is detected. In such systems the mechanisms for interference control are of essential importance. On the other hand, delay and energy efficiency requirements call for intelligent data queue handling for transmission over fading channels. In this work we study the use of stochastic control methods on the transmitter data queue to optimize the energy useage of an opportunistic user in a cognitive radio system. Radio sensors are used to monitor the interference levels generated by the opportunistic user, and control the opportunistic transmissions in order to not exceed the allowed average interference level. The student will implement a system model in MATLAB and find its behavior through simulations.

Keywords*— *Primary user, Cognitive Radio, Secondary User, DSA, Interference Queue

I. INTRODUCTION

This Today wireless systems take up more and more of the frequencies that are available. Most of them are licensed to mobile and telephone operators, other for high speed wireless internet. While new wireless systems are developed there seems to be a lack of free frequencies, and most of the unlicensed frequencies is already packed with users. These high demands on frequencies require the new system to build upon new types of technology. One of them called cognitive radio, which allow the re-use of spectrum. This technology takes in to account other users on the network, the spectrum and channel state. The idea of cognitive radio was first introduced by Joseph Mitola III in 1998, and the term cognitive radio identifies (from [1]) the point at which wireless personal digital assistants (PDA) and the related networks are sufficiently computationally intelligent about radio resources and related computer-to-computer communications to: a) detect user communications needs as a function of use context, and b) to provide radio resources and wireless services most appropriate to those needs. What we are interested in is a spectrum agile radio. We use a more simple approach by reusing the spectrum and implementing a form of interference control too keep the average received level at a constant level. One problem with the cognitive radio is that the secondary user do not know if any primary user that's in its range are already listening to another primary user outside the listening range. At this point the secondary user would just start transmitting and thus interfering with the primary user. One approach to protect the primary user is to set up a sensor that listens on the secondary user as well as the primary user, and we solve the problem with interference at the sensor. Since the secondary user does not know of the primary user transmitting, he thinks it is okay for him to transmit, thus interfering for the primary user. The sensor should then give feedback to the secondary user that it should lower the transmission power. At this point we need a data queue at the secondary user that control the arriving data, a power allocation method to allocate power based of the channel state between secondary user TX-RX and the interference history received from the sensor. We do this to keep the data rate between the secondary users high while trying to limiting the average received interference at the sensor. The and one interference queue at the sensor that just hold the interference size. If there are no primary users transmitting that the sensor senses, the transmission of the secondary user is okay. The goal of the work is to maximize the data rate between the secondary transmitter and receivers, while limiting the interference with the primary user, using a sensor network. We will focus on three things, the data queue at the secondary transmitter, the power allocation and a virtual interference queue at the sensor. This virtual queue is modeled on the principles a ordinary queue, so that we can use the same stability criteria.

II. OVERVIEW

Another assumption is based on the propagation environment; we assumed that the channel is located in a high density area, where there are a lot of objects creating many paths (multipath) from the transmitter to receiver. In these environments you typically do not have any form of line of sight (LOS) component, and we assume that the channel in these areas has a Rayleigh fading distribution.

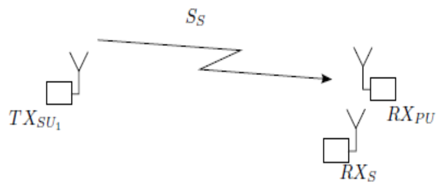

Fig.1: Display of sender and transmitter

This channel has an exponential probability density function (PDF) of the squared envelope, because it exists of a multipath that distorts the phase and quadrature component. By knowing this we can emulate a channel that have the same statistical probabilities.

It is the sensor that give feedback to the secondary user about interference, and we assume that the sensor and primary user is close to each other, then it is necessary to know that the channel statistics. If we cannot assume the same statistics on the propagation environment, then we cannot assume that the sensor and primary user have the same signal strength, and the interference measured might not be the same as at the primary user.For other parts of the system we use the assumption that the flow of data in to the queue is less than the data capacity through the channel between TX_{SU1} and RX_{SU2}. If the flow in is larger than the flow out, it is possible to force this assumption by utilizing package dropping.

III. SYSTEM MODEL

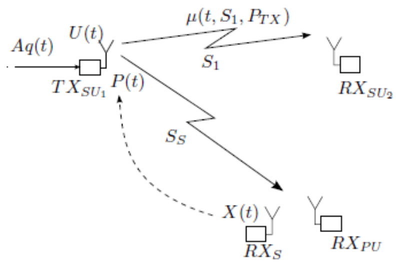

Fig.2: Sketch of the system principle

Our system design in figure 2 is designed to simulate the effects of using a sensor to limit the interference level created by communication between two secondary users, while trying to achieve a high data throughput between them. For this purpose you need to control the data flow in to the system, and out of the system, thus creating a data queue where the data that arrives should be queued before transmitting. Controlling the interference means that you would need a form of transmit power control, that control the power to a level where it do not interfere with the primary user. Here you need to spend as much power as possible without interfering with a primary user to achieve a high data throughput. That when the sensor should do its purpose, creating an interference queue that keeps track of the interference level from the secondary user. By assuming that the channel between the secondary user and the sensor share the same statistics as the channel between the secondary user and primary user, we can use the interference data from the sensor to control the secondary user transmit power.

The thought is that a lot of sensors is placed randomly around a location, and would probably be close to a primary user. If the sensor senses a secondary user transmitting, it would start monitoring that user, and give feedback to it in case it start interfering too much. Since the sensor and primary user are not located at the same place, you have to use the assumption that the channel between $TX_{SU1} – RX_S$ and $T X_{SU1} – RX_{P U}$ have the same statistics. the assumption that the sensor and primary user have the same statistics, we can assume that the primary user have the same average received power as the sensor. Our approach is to create an interference queue at the sensor, and then stabilizing it. If we manage to stabilize the interference queue, we could stabilize the interference that the secondary user cause. This is done by lowering the transmission power at the secondary user, using data from the interference queue at the sensor.

A. Different functions of the system

The different functions of the system in fig.2 are as follows

- The data queue U (t) - Is the transmit buffer for the transmitter $T X_{SU1}$, and hold the size of the data queue at a given time. It has the arrival process Aq(t) as input, and depends on the transfer rate function μ(t, P, S) as output.
- The arrival process Aq(t) - Models the random arrival of data from the upper transportation layers in to the $T X_{SU1}$.
- The channel state S(t) - is the channel state between the secondary users and sensor.
- The function μ(t, P, S) - is the function that calculate how much data is transmitted from the $T X_{SU1}$ to the RX_{SU2} , depending on the transmit power P (t) and S_1.
- Interference queue X (t) - is at the receiving sensor RX_S and holds the interference, and it depends of S_S and P (t).
- Power allocation function P (t) - Implemented in $T X_{SU1}$ and uses X (t) from the sensor, but need to operate if there is no received interference from the sensor.

B. How the queue is handled

The queue is handled by subtracting amount transferred from the size of the queue then adding a random arrival Aq(t). By storing the queue state at every time instant, we can find the approximate of how long data is stored before transmitted, by taking the mean of the queue size.

The next value of the queue size is calculated with the following equation:

$$U(t+1)=\begin{cases} U(t) - \mu(t, P(t), S_1(t) + A_q(t) & if\ U(t) \geq \mu\big(t, P(t), S_1(t)\big) \\ A_q(t) & else \end{cases}$$

The queue would be stable if and only if the mean arrival is less or equal to mean transmission data.

C. The arrival process

The idea of the queue arrival process is to simulate random arrival to be transmitted. The current setup of the queue arrival is:

$$A_q(t)=\begin{cases} n & if\ k < p_R \\ 0 & if\ k \geq p_R \end{cases}$$

where n ∈ [1, N] and k∈ [0, 1] is a random number with uniform distribution. The arrival rate $N \cdot p_R \leq$ instantaneous Shannon capacity for the channel between the two secondary users, where p_R is the probability of receiving data to the queue and N is max amount of bits that can arrive. This limitation is set because of the assumption that the flow in to the system should be less or equal to the flow out of the system.

D. Channel state

The channel state is a description on how good the signal from the transmitter can be "read" at the receiver. To generate the channel state, the Matlab function random('exp',<dimension>·<mean>) was used.

E. The transfer function μ

The transfer functions purpose is to calculate how much data we manage to transmit over the channel, given a channel state S(t) and the transmit power P (t) calculated in section 4.1.6. It origins from Shannon's capacity theorem, found in

$$\mu(t,\ P\ (t),\ S(t)) = \log_2(1 + P\ (t) \cdot S_1(t))$$

where P (t) is the transmit power and $S_1(t)$ is the channel state between the secondary T X and RX.

F. The virtual interference queue

By using the sensor to update the interference level, and returning the value to the secondary user. In a similar virtual power queue was used to enforce a transmit power constraint. Here we hope to stabilize the virtual interference queue to stabilize the interference. If this is possible the hope is to get as much throughput to the secondary receiver with stable interference to the primary user.

The interference queue's next value is updated every time instant, and depends on the transmit power P (t) from the secondary user, the channel state $S_s(t)$ between SU_1 and sensor and the average interference X_{av} . The average interference is how much interference is allowed to be over an average. This value can be tuned to the interference level you allow at the sensor, but would also change the data throughput between the T X_{SU} and RX_{SU} . A high X_{av} allow for higher data throughput, and a low value for less data throughput. The X_{min} control maximum power level, if set to 0 would make it possible for the transmit power to become infinity. If we manage to stabilize the interference queue, we should be able to stabilize the interference done to the primary user/sensor. The interference queue can only be stable if the average received P (t) · S(t) is less than X_{av} .

$$X(t+1)=\begin{cases} X(t) - P(t).S_s(t) & if\ X(t) > X_{av} \\ P(t).S_s & if\ P(t).S_s(t) > X_{min}\ and\ X(t) < X_{avg} \\ X_{min} & if\ P(t) = 0\ and\ X(t) < X_{avg} \end{cases}$$

G. Transmit power allocation

The goal of the transmit power allocation is to get an adaptive system, one that tries to transmit as much data as possible on good channel states. The system depends on the channel state between the secondary TX and RX, the data queue size and the interference registered at the sensor. The interference queue explained in section 4.1.5, transmit the interference level back to the TXSU so that the value can either increase or decrease the power level. The power allocation is done the following way:

$$P(t)=\begin{cases} Ppeak & if\ Ppeak \leq P(t) \\ 2.U(t)\frac{2.U(t)}{X(t)} - \frac{1}{s_1\ (t)} & if\ 0 < P(t) < Ppeak \\ 0 & if P(t) \leq 0 \end{cases}$$

As you can see in equation 4.5 it allocate the power to use based on the interference queue X(t) explained in equation 4.4. Both of the equations have a channel state, the power allocation use the current channel state S1, and the interference queue use the channel state SS. The power allocation is also part of the water filling solution $\frac{1}{\gamma_0}$ - $\frac{1}{\gamma_D}$ but here the threshold $\gamma_0 = \frac{X(t)}{2.U(t)}$ and would change depending on how large the data queue or interference queue changes.

H. The capacity of the system

To figure out where to limit and start the simulations, we have to determine the capacity of a Rayleigh fading channel with an average signal to noise ratio (SNR) of 1. We assume we have an average power of 1 and that the channel is slowly varying. The capacity of the system were then calculated numerical using Newtons method, to find a unique x0 so that f(x0) = 0 using formula

$$f(x)=\frac{e^{-x}}{x}-E_1(x)-\bar{\gamma}$$

where $x = \frac{\gamma_0}{\gamma}$ En(x) is the exponential integral of order n, 0 is the SNR at the Shannon capacity and $\bar{\gamma}$= 1 is the average carrier-to-noise (CNR). Using Newton's method:

$$x_{n+1}=x_n\frac{f(x_n)}{f'(x_n)}$$

where f'(x) = $e^{-x}$is the derived of f(t). Computing a new xn+1 trying to get as close as possibleto 0. which is

$$\frac{C_{opra}}{B}=log_2(e)E_1(\frac{\gamma_0}{\bar{\gamma}})$$

IV. CONCLUSION

An opportunistic transmission mode gives a higher received power at the secondary receiver. Using the sensor implementation helped control the power level at the secondary transmitter, with an average received interference of Xav = 1 at the sensor. One of the problems occurred was that we could not achieve close to the theoretical capacity of the channel. Much of this was because of the interference constrain in the power allocation, caused good channels between the two secondary users go to waste because of a high interference level at the sensor. Setting a peak power limitation would spread the transmissions and keeping a low interference at the sensor. This would stop the virtual interference queue from peaking, and created the interference queue more stable, allowing a higher arrival rate.

For higher arrival rate then the capacity of the system would cause the power to go in to constant transmission.

For arrival rates higher than the capacity of the system, it is possible to use package dropping at the arrival process. But this would not cause any increase in capacity. Decreasing the Xav decreases the transmit power from the secondary user, but would cause the data queue to become unstable as long as arrival rate were higher or equal to Xav. At lower arrival rates there was a peak in the factor between the power at secondary receiver and the power at the sensor. For future work on this subject, it would be interesting to study more of the effects adjusting the peak power to achieve better efficiency. Implementing package dropping to keep the data queue stable.

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