Abstract: We explore the coexistence potential of cognitive system based on interference temperature. The characteristic feature of this interference temperature metric would be their ability to adapt the transmit power and bandwidth of their communication scheme to maximize the QoS for the secondary users while minimizing the interference to the primary users. Considering generalized interference temperature model as a baseline [2], we investigate the throughput variation of the secondary user in the heterogeneous communication environment. Also we propose a certain coexistence scheme that allocates bandwidth and transmit power of secondary user without harming the primary user using the concept of interference temperature.

1. Introduction

Recently, many kinds of wireless systems becoming services for satisfying demand of high quality communication service. Along with this, when considering the increase of wireless network users and QoS(Quality of Service) of various users, cognitive radio techniques have been proposed as a means to implement efficient reuse of primary spectrum. That is, cognitive radios are promising solutions to the problem of overcrowded spectrum.

Also the FCC (Federal Communications Commission) has recommended that optimum coexistence of heterogeneous communication users could be realized by deploying interference temperature metric[1, 3].

In this paper, consider the following communication scenario which we will refer to as the interference channel.

As a means of quantifying and managing interference, interference temperature is defined as a measure of the RF (Radio Frequency) power available at a receiving. It is the temperature equivalent of the RF power available at a receiving antenna per unit of bandwidth, measured in units of Kelvin [2].

Let $T_i(f_c, B)$ be the interference temperature to the secondary user transmitter for channel $c$, with central frequency $f_c$ and bandwidth $B$.

$$ T_i(f_c, B) + \frac{MP_{se,ts}}{kB} < TH_c $$  (1)

Where $M$ is path loss in transmission between secondary transmitter and primary receiver centered at frequency $f_c$. $P_{se,ts}$ is the average interference power at the primary receiver in watts. Also $TH_c$ is the interference temperature threshold and $k$ is Boltzman’s constant ($1.38 \times 10^{-23}$ Joules per Kelvin). In this paper, the interference temperature threshold and background noise temperature are set to each $47.83 \times 10^3 K$ and 122.15 $K$. Using above equation (1), the received signal power can be limited as

$$ P_{se,ts} < \frac{kB}{M}(TH_c - T_i(f_c, B)) $$  (2)

Through the spectrum sensing technique, secondary transmitter computes above equation (1) and (2). Namely, it is initial coexistence processing from secondary transmitter viewpoint.

2.2 Calculation of secondary capacity

To guarantee the required SINR (Signal to Interference plus Noise Ratio) level and QoS at the secondary user, we consider capacity of secondary user receiver.

$$ C = B \cdot \log_2 \left(1 + \frac{L \cdot P_{se,ts}}{kBT_i(f_c, B)}\right) $$  (3)

Here, $L$ is path loss in transmission between secondary transmitter and receiver pair. By computing above equation

2. Evaluation method

2.1 Calculation of secondary transmission power

Figure 1. The interference channel with three primary users AP_A, AP_B, AP_C and secondary user.
Consider the interference scenario shown in Figure 1, the defining assumption for these models is that the secondary transmitter has a priori knowledge of the primary user’s interference temperature limits, bandwidth and path loss. From this assumption, equation (3) can be rewritten as

\[
C = B \cdot \log \left( 1 + \frac{L \cdot P_{se,tx}}{kBT_f (f_c, B)} \right) = B \cdot \log \left( 1 + \frac{L \cdot (T_L (f_c, B) - T_i (f_c, B))}{kBT_f (f_c, B)} \right) = B \cdot \log \left( 1 + \frac{L \cdot T_L (f_c, B) - T_i (f_c, B)}{M \cdot T_i (f_c, B)} \right)
\]  

(4)

Here, \(T_L (f_c, B)\) is interference temperature limits. Figure 2 is the spectrum arrangement showing the interference temperature limits at the primary users.

Figure 2. The interference temperature of the primary users.

For the secondary user’s capacity to achieving the QoS for the secondary users but minimizing the interference to the primary users, we adjust the secondary transmitter bandwidth. Figure 3 shows the adaption process of secondary transmitter bandwidth.

Transmission possible power of the secondary transmitter could be calculated individually about the primary user. That is,

\[
P_{se,tx, A} < \frac{kB_A}{M_A} (T_L (f_A, B_A) - T_i (f_A, B_A))
\]  

(5)

\[
P_{se,tx, B} < \frac{kB_B}{M_B} (T_L (f_B, B_B) - T_i (f_B, B_B))
\]  

(6)

\[
P_{se,tx, C} < \frac{kB_C}{M_C} (T_L (f_C, B_C) - T_i (f_C, B_C))
\]  

(7)

where \(P_{se,tx, A}\), \(P_{se,tx, B}\) and \(P_{se,tx, C}\) is the possible transmitter power of the secondary transmitter. This value satisfied transmission power constraints given by

\[
P_{se,tx, select} = \min \left( P_{se,tx, A}, P_{se,tx, B}, P_{se,tx, C} \right)
\]  

(8)

where \(P_{se,tx, select}\) is the optimum transmission power at the secondary transmitter and \(P_{max}\) is the transmission power with no primary user communication environment.

Consider the interference scenario shown in Figure 1, the background noise and remaining interference power which excepts the primary user given by

\[
I_c (f_c, B) = \frac{1}{kB^2} \int_{f_c - B/2}^{f_c + B/2} S(f) \, df
\]  

(10)

The average power of the total bandwidth is

\[
P_L (f_c, B) = \frac{1}{B_{total}} \sum_{l=1}^{L} B_l \cdot P_{se,tx,l}
\]  

(11)

where \(L\) is the number of primary user. In this paper, primary user indexed with A (Bluetooth), B (WLAN) and C (Zigbee). Figure 4 showing the relationship of the minimum sensitivity level from respectively primary user and the transmission possible power at the secondary transmitter.

Figure 4. Relationship of the minimum sensitivity level and the transmission possible power.

From equation (9), (10) and (11), equation (4) can be rewritten as
\[ C = B \log_2 \left( 1 + \frac{L \cdot P_{\text{se,\text{ac}}}(f_c, B)}{P_f(f_c, B) + P_i(f_c, B)} \right) \]  

3. Experimental data

To coexist with primary user, we carried out the realistic simulation by the concept of interference temperature that is based on spectrum sensing technique in 2.4GHz ISM band. Also assuming that each user device’s location and relative distances is known at the relation devices in free-space path loss environment. Each user is presumed to transmit as well as receive. Related spectrum allocation and parameters for simulation are showed in Figure 5 and TABLE I respectively.

![Figure 5. Spectrum allocation with multi-user environment.](image)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>WLAN</th>
<th>Bluetooth</th>
<th>Zigbee</th>
<th>Secondary user</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center Frequency (MHz)</td>
<td>2437</td>
<td>2423.5</td>
<td>2475</td>
<td>2450</td>
</tr>
<tr>
<td>Bandwidth (MHz)</td>
<td>22</td>
<td>1</td>
<td>2</td>
<td>Variable</td>
</tr>
<tr>
<td>Transmit power(dBm)</td>
<td>14</td>
<td>0</td>
<td>0</td>
<td>Variable</td>
</tr>
<tr>
<td>Required BER</td>
<td>(10^{-5})</td>
<td>(10^{-5})</td>
<td>(10^{-3})</td>
<td>(10^{-3})</td>
</tr>
<tr>
<td>Required SNR(dB)</td>
<td>8.4</td>
<td>2</td>
<td>2.5</td>
<td>7.56</td>
</tr>
</tbody>
</table>

The interference temperature limit and background noise temperature are set subject to satisfying the required BER(Bit Error Rate) of primary as \(10^{-5}\). Furthermore, secondary user also requires \(10^{-5}\) BER. As we increase bandwidth of secondary user until satisfying 52Mbps, we can calculate the interference temperature and the capacity according to determined bandwidth. To achieve the optimized bandwidth and transmit power of secondary user satisfying required capacity, we applied the optimization algorithm methods.

4. Evaluation result

The bandwidth and transmit power of secondary user can be chosen by considering the SINR (i.e., 52Mbps) in secondary receiver. Allowable capacity can be derived according to the bandwidth of secondary user as shown in Figure 6. Optimized parameters of secondary user through the simulation results are listed in TABLE II.

![Figure 6. Allowable capacity according to bandwidth of secondary user.](image)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Optimized value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center frequency</td>
<td>2450 MHz</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>16.5 MHz</td>
</tr>
<tr>
<td>Transmit power</td>
<td>WLAN : -20.75 dBm, Zigbee : -23.44 dBm, Bluetooth : -8.75 dBm</td>
</tr>
</tbody>
</table>

According to the TABLE II, the secondary user flexibly utilize the frequency band for coexisting with primary user.

In this paper, we have investigated how to optimize the transmit power and bandwidth of secondary user while minimizing the interference influence of each user in multi-user channel environment. Numerical results revealed that the proposed schemes can achieve near-optimal bounds for coexistence between the primary user and secondary user.

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References

