Experiment Report

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Principles of Communications

Lab4: High sensitive capture mechanism

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1. Aim of the Project

Use LabVIEW and USRP digital experimental platform for the transmission of text messages. Use high sensitive packet capture mechanism for the complete digital transmission link design. Compare the difference of the packet capture sensitivity and transmission distance under the two kinds of capture mechanism of the receiver.
2. Principles

The whole processes are all we have learnt from the theory class. In the lecture notes, the whole communication system is shown as the following figure.

![Block diagram of the digital communication system](image.png)

In this experiment, we only take digital communication system into consideration. So the transmitter part starts from source coding and the receiver part ends with source decoder.

**Transmitter**:

![Digital baseband link of transmitter](image.png)
Figure 3. Digital baseband link of receiver
3. Capture Mechanisms

The receiver decides whether to revert ACK signal or not according to the verification result of the received packets. That is, revert ACK if the result is correct, otherwise the receiver continues to wait for packet retransmission. Transmitter resends a packet until it receives ACK message, then proceeds to the next packet sent.

Packet detection is to extract the header of the valid signal in the channel. We know that under normal circumstances, signal energy is greater than the noise energy.

The simplest algorithm for finding the start edge of the incoming packet is to measure the received signal energy. When there is no packet being received, the received signal consists only of noise. When the packet starts, the received energy is increased by the signal component, thus the packet can be detected as a change in the received energy level.

3.1 Example Mechanism

The example only divide the samples into groups with size “Bin Size”, and then take the sum of each group, so that we can get the average power. In subVI “sub_est_noise_power” has the main program. The logic function can be interpreted as this:

\[
\text{Sample Stream} \quad \Sigma / L \quad \text{Average Power} \\
0 \\
1 \\
\vdots \\
L-1 \\
L \\
L+1 \\
L+2 \\
\vdots \\
2L-1 \\
2L \\
2L+1 \\
\vdots \\
\text{Size } N \\
\]

\[
\begin{align*}
\sum / L & = \frac{0}{1} > \text{signal power} \\
\sum / L & = \frac{1}{2} > \text{noise power} \\
\sum / L \leq \frac{(M+m)/2, 10^{-6}, 100m} & \rightarrow \text{Threshold}
\end{align*}
\]
Thus the number of complex multiplications is reduced to one per received sample. The response of this algorithm is shown in Figure 3. The figure shows the value $m_n$ for IEEE 802.11a packet with 10dB Signal to Noise Ratio (SNR) and sliding window length $L = 32$. The true start of the packet is at $n = 500$, thus in this case the threshold could be set between 10 and 25.

Figure 3. Received signal energy based packet detection algorithm [3]

Here follows the program diagram of example.

Figure 4. subVI “sub_est_noise_power” of example
3.2 Single Window Complementation

The decision variable $m_n$ is then the received signal energy accumulated over some window of length $L$ to reduce sensitivity to large individual noise samples.

$$m_n = \sum_{k=0}^{L-1} r_{n-k}^* r_{n-k} = \sum_{k=0}^{L-1} |r_{n-k}|^2$$  \hspace{1cm} (1)

Calculation of $m_n$ can be simplified by noting that it is a moving sum of the received signal energy. This type of sum is also called a sliding window. The rationale for the name is that at every time instant $n$, one new value enters the sum and one old value is discarded. This structure can be used to simplify the computation of Equation (1). Equation (2) shows how to calculate the moving sum recursively.

$$m_{n+1} = m_n + |r_{n+1}|^2 - |r_{n-L}|^2$$  \hspace{1cm} (2)

Thus the number of complex multiplications is reduced to one per received sample.

In subVI “sub_est_noise_power 1” has the main program. The logic function can be interpreted as this:

Here follows the program diagram of example.
3.3 Double Window Complementation

A high sensitive method of packet capture can refer to [3]. The double sliding window packet detection algorithm calculates two consecutive sliding windows of the received energy. The basic principle is to form the decision variable $m_n$ as a ratio of the total energy contained inside the two windows. Figure 7 shows the windows A and B and the response of $m_n$ to a received packet. A and B windows are considered stationary relative to the packet that slides over them to the right. It can be seen that when only noise is received the response is flat, since both windows contain ideally the same amount of noise energy. When the packet edge starts to cover the A window, the energy in the A window gets higher until the point where A is totally contained inside the start of the packet. This point is the peak of the triangle shaped $m_n$, and the position of the packet in Figure 7 corresponds to this sample index n. After this point B window starts to also collect signal energy, and when it is also completely inside the received packet, the response of $m_n$ is flat again. The packet detection is declared when $m_n$ crosses over the threshold value Th.

Equation (3) shows the calculation of the A window value and Equation (4) the calculation for B window. Both $a_n$ and $b_n$ are again sliding windows, thus the computation can be simplified in the same recursive manner as for the energy detection window. Then the decision variable is formed by dividing the value of the $a_n$ by $b_n$. 

![Figure 6. Block diagram](image-url)
In subVI “sub_est_noise_power 2” has the main program. The logic function can be interpreted as this:

\[
\begin{align*}
    a_n &= \sum_{m=0}^{M-1} r_{n-m}^* r_{n-m} = \sum_{m=0}^{M-1} |r_{n-m}|^2 \quad (3) \\
    b_n &= \sum_{l=0}^{L-1} r_{n+l}^* r_{n+l} = \sum_{l=0}^{L-1} |r_{n+l}|^2 \quad (4) \\
    m_n &= \frac{a_n}{b_n} \quad (5)
\end{align*}
\]

Figure 7. The response of the double sliding window packet detection algorithm \(^{[3]}\)
Here follows the program diagram of subVI “sub_est_noise_power 2”.

Figure 8. Block diagram
4. Contents related to USRP

4.1 Results
The receiver display is shown as below. The figure shows the successful reception and the figure shows a high error probability.

![Receiver display](image)

Figure 9. Receiver display when packet loss is small
As shown in the foregoing introduction, the high sensitivity capture system overwhelms the other for its tolerance of long distance and low transmission power. In our experiment, its advantage is illustrated by experimental data. As you can see from table 1 and table 2 below. Receiver gain is fixed at 0dB and the distance refers to the distance from two antennas.

<table>
<thead>
<tr>
<th>Distance (cm)</th>
<th>Required gain for single window(dB)</th>
<th>Required gain for double window(dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>14</td>
<td>6</td>
</tr>
<tr>
<td>32</td>
<td>17</td>
<td>14</td>
</tr>
<tr>
<td>38</td>
<td>20</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 1. minimum gain under fixed distance
### Table 2. maximum under fixed gain

<table>
<thead>
<tr>
<th>Receiver gain (dB)</th>
<th>Max distance for single window(cm)</th>
<th>Max distance for double window(cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>19</td>
<td>38</td>
</tr>
<tr>
<td>17</td>
<td>16</td>
<td>42</td>
</tr>
<tr>
<td>20</td>
<td>45</td>
<td>107</td>
</tr>
</tbody>
</table>

From the table, the high sensitivity mechanism is superior to the single window one, since the required gain to ensure a secure transmission is lower and the maximum transmission distance under certain gain is longer. Results meets our expectation well, however, after careful scrutiny, we find that, the data vary dramatically.

In table 1, to ensure a perfect capture accuracy, the minimum required gain for double window decrease as the distance increase. To illustrate that aberrance, these two group of data are collected in different time, as the environment factor may impact on the result. These factors are going to be discussed in the 4.2 section.

#### 4.2 Questions and answers

Q1: What is the impact of the threshold?

In [3], the author derived the following formula to show the optimal value of the peak value of m, the ratio of two sliding windows.

\[
m_{\text{peak}} = \frac{a_{\text{peak}}}{b_{\text{peak}}} = \frac{S + N}{N} = \frac{S}{N} + 1
\]

So when SNR equals to 10dB, S/N equals to 10, so the peak value is supposed to be 10. When the SNR increases, the peak value also changes with the reference to SNR. In our experiment, we tested different threshold values and the result corresponds with the estimation. When the distance become longer, noise interference become larger and SNR decreases, so the small threshold overwhelms.

As discussed in [3], the double window scheme overwhelms the single window scheme because its high tolerance to the varying SNR. In our experiment, the threshold between 1.1 to 1000 are all tested, and
normally 2~100 all performs well, the corresponding SNR is between 1~200, if we regard half of the peak as the optimal threshold, and finally, we set the threshold as a dynamic value so as to get the optimal performance. This method is also utilized in the provided example.

Q2: Why the performance vary significantly in different conditions?

The aberrance conditions are shown in table 1 and 2. Even if we take experiment under same conditions, these aberrance also happen. So we are very curious about this circumstance. Although we didn’t take scientific experiments to confirm our hypothesis, we think that some hypotheses can illustrate the results. Firstly, some external factors influence the performance. These factors are shown in the next question. Secondly, some internal factors such as the computing capability of the computers will also change the performance.

Q3: Analyse possible environmental factors that may influence the performance.

In this question, we try to give an illustration about possible factors, which may impair the performance.

a) Relative positions of two USRPs.
In the experiment, we find that when the USRP are not align on the same line, i.e. antennas of one USRP are not direct opposite to antennas of the other one. The packet loss tend to be larger and when these two USRP are facing to the same direction, signal cannot transmitted to the receiver at all.

b) Reflection of the table top
We observe the influence of this factor because when we put USRPs on the table instead of the chairs, the performance increases. As for the signal reflection increase the SNR rate, the performance increase is reasonable.

c) Interference of other signals
Interference of other signals will also impair the performance, such as the phone signal and voice signal. For example, when we put the calling phone between antennas, packets loss increase significantly.

d) Other environmental factors
Some other factors are not discussed specifically. However, the influence is very easy to see, such as the wind and air density.
These not be verified by specific data and the performance loss cannot be evaluated by certain degrees. But the change are shown in our experiment, and its influence is rational. So the experiment should take these factors into consideration.
Reference: