A Simple Superresolution Method of Multipath Delay Profiles

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Abstract:
Time resolution of multipath delay profiles measured by using autocorrelation of pseudonoise(PN) code sequence is generally limited by the chip rate of the PN code sequence. In this paper, we proposed a simple method to improve the time resolution of delay profiles measured by the PN correlation method. Effectiveness of this method is demonstrated by an indoor wireless propagation experiment using circularly polarized wave at 900MHz, and the number of multipath is given unambiguously.

Keyword: Superresolution, Multipath Delay Profile, Circular Polarization, Indoor Propagation

I. Introduction
Since most people stay in buildings or around buildings for most of their time, an important consideration in successful implementation of personal communication services (PCS) is indoor radio communications, i.e., transmission of voice and data to people on the move inside buildings. As we all know, delay distortion due to multipath propagation is a serious cause of channel degradation [1]. So, the information of propagation delay in buildings is very important.

Circular polarized wave's delay profile measurements were made in a typical Chinese office building, using spread spectrum correlator measurements. Although high-resolution delay profiles are necessary to analyze indoor radio propagation, the delay-time resolution is generally limited by the chip rate of the PN sequence. So, in order to get reliable results, we proposed a quite simple method to improve the time resolution of delay profiles measured by the PN correlation method. It proved to be very effective. The data analysis provides a statistical description of the Circular polarized wave indoor propagation by determining the number of paths from the measured impulses.

The organization of this paper is as follows: Section II describes the measurements; In Section III, we propose the superresolution algorithm to improve the time resolution; Analysis of the number of multipath and conclusion are presented in Sections IV and V, respectively.

II. Measurement Procedure
A spread spectrum sliding correlator channel sounding system was used to measure the power delay profile. The m-sequence used was 63 bits in length and the carrier frequency was 900MHz. Chip rates at the transmitter and the receiver were 40Mbps and 39.996Mbps respectively; it takes 15.75 milliseconds for the two sequences to shift 63 chips relative to each other to accomplish a complete correlation process. The output of the receiver were sampled at 40Ksps by an A/D converter and stored in PC for any further processing. Circular polarized antennas were equipped at both transmitter and receiver.

Measurements were taken in several rooms and corridors in the 2nd floor of the East Wing of Main Building in Tsinghua University. Data were recorded under various situations with or without a Line Of Sight (LOS) path, at different distance between the transmitter and the receiver and in rooms differed in their sizes.

III. Superresolution of Measured Data
Prior to any further processing, the recorded raw data cannot discriminate any two multipath components...
arrive at the receiver within a time interval less than 25 μs. In other words, the smallest difference between path lengths that can be resolved in the delay profile diagram is 7.5 meter. This resolution is not enough to study the indoor propagation, since it is even greater than the dimensions of rooms. Some algorithms have already been proposed to solve the problem of this kind[2], but they are generally large-computation involved. We developed a relatively simple method to improve the performance of the raw data, and successfully reduced the minimum discriminable difference between path lengths to about 3m.

A. Mathematical Model

In a time invariant radio channel, its impulse response has the following form:

\[ h(t) = \sum_{i} a_i e^{-j(\omega_i \cdot t)} \delta(t - \tau_i) \]

Index \( i \) indicates the \( i \)th multipath component, \( \tau_i, a_i, \phi_i \) represent the time delay, amplitude gain and excess phase shift of the \( i \)th multipath component at the desired frequency. Suppose the transmitted signal is:

\[ s_i(t) = m(t) \cos(\omega_c t) \]

here \( m(t) \) is the m-sequence and \( \omega_c \) is the carrier frequency, the signal reached the antenna of the receiver could be represented as:

\[ s_i(t) = \sum_{i=1}^{m} a_i m(t - \tau_i) \cos[\omega(t - \tau_i) + \phi_i] \]

After correlation with the internally generated in the receiver, the output baseband signal is:

\[ s_o(t) = \sum_{i=1}^{m} a_i R(\frac{t}{K} - \tau_i) + n_o(t) \]

\( R(t) \) is the autocorrelation of \( m(t) \) and \( K \) is the amplify factor, which is defined as the ratio of the chip rate to the difference between the chip rates of the transmitter and the receiver. \( n_o(t) \) is the output zero-mean Gauss baseband noise. Prior to any processing, the minimum time resolution is determined by the half width of the main peak of \( R(t) \). If we can replace \( R(t) \) with a narrower waveform such as \( \delta(t) \) in the expression of \( s_o(t) \), the resolution will be largely improved. It is easy to prove that \( s_o(t) \) can also be represented in another form:

\[ s_o(t) = R(\frac{t}{K}) \ast |h(t)| + n_o(t) \quad \quad (1) \]

Operator \( \ast \) means convolution of two signals. Now we can see that the problem can be solved by deconvoluting \( R(t/K) \) from \( s_o(t) \). Deconvolution can easily be done in the frequency domain since the Fourier Transform of \( s_o(t) \) is simply the multiplication of the Fourier Transforms of \( R(t/K) \) and \( |h(t)| \). So the amplitude of the impulse response can be recovered from \( s_o(t) \) through the following formula:

\[ |h(t)| = F^{-1} \left[ \frac{F[s_o(t)] - F[n_o(t) + |h(t)|]}{F[R(t/K)]} \right] = F^{-1} \left[ \frac{S_o(\omega) - N_o(\omega)}{R(\omega)} \right] \]

B. Implementation

From formula (1), we can see that \( R(t/K) \) is very crucial in the superresolution process. Due to the band limit of the receiver, it no longer retains the theoretical shape as a triangle. But it can be easily obtained by recording the output waveform of the receiver when it is connected directly with the transmitter by a coaxial cable. No multipath component will present at that situation, so the recorded waveform shows the shape of \( R(t/K) \). One problem is the zero points of \( R(\omega) \) as shown in Fig.1(b), since they will cause some frequency components to go infinity. To avoid this, we set a threshold \( \epsilon \) and substitute all the amplitude of \( R(\omega) \) below \( \epsilon \) with \( \epsilon \) as shown in Fig.1(c). Another problem is how to deal with the noise, since it is impossible to get a deterministic form of \( N_o(\omega) \). We made an estimation for it as follows:

\[ N_o(\omega) = \begin{cases} 0 & \omega < \omega_c \\ S_o(\omega) & \omega \geq \omega_c \end{cases} \]
Here $\omega_p$ is the bandwidth of receiver.
In this estimation, we ignored the existence of noise at low frequencies within the bandwidth of the receiver, because the signal level is much greater than the power of noise in this region; at relative high frequencies, the signal level ought to be very small (nearly 0) due to the band limit. So we cleared $S_0(\omega)$ to 0 in this region. Fig.2 shows an example of the recorded profile before and after the process. The superresolution effect is quite obvious.

IV Result of Analysis
Here, the number of multipath components $N$ was found by counting all multipath components within $\alpha$ dB of the strongest paths for $\alpha = 3, 5, 10, \text{and } 15$. The results are summarized in Table 1. ($\mu$: mean value of $N$, $\sigma$: standard variance)

<table>
<thead>
<tr>
<th>$\alpha$</th>
<th>Room - Room</th>
<th>Room - Corridor</th>
<th>Corridor - Corridor</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 dB</td>
<td>1.5</td>
<td>1.4</td>
<td>2.6</td>
</tr>
<tr>
<td>5 dB</td>
<td>1.9</td>
<td>1.8</td>
<td>3.2</td>
</tr>
<tr>
<td>10 dB</td>
<td>3.9</td>
<td>2.4</td>
<td>7.1</td>
</tr>
<tr>
<td>15 dB</td>
<td>8</td>
<td>7.1</td>
<td>14.0</td>
</tr>
</tbody>
</table>
An examination of this table shows that:

i) The value of $\mu$ increases when $\alpha$ increases. This is expected because more components are included in the calculation of N with increasing $\alpha$. [3]

ii) For the same $\alpha$, Room-Corridor case has the highest $\mu$. The reason is that there is no Line Of Sight path at this case, while Line Of Sight path exists in the other two cases.

iii) Compared with experiments [4] using linearly polarized wave in the same place, Only for the case Room - Room and for $\alpha = 5$ or 10dB, There is obviously fewer path when using circularly polarized wave. ([4] shows that $\alpha = 5$dB, $\mu = 3.8$; $\alpha = 10$dB, $\mu = 7.3$)This is due to the fact that in Room - Room case there are relatively high single reflective power, which can be suppressed effectively by the use of circular polarization. [5]

V. Summary

A simple method to improve the time resolution of delay profiles measured by the conventional PN correlation method was reported. The applicability of the method has been demonstrated by applying this method to delay profiles obtained in a typical Chinese office building. The number of multipath in the building and some conclusion are also reported to directly investigate the effects of using circularly polarized wave.

VI. Acknowledgement

All the experiment data used in this paper were recorded by Mr. Ding Ding in 1998. [4]

References


