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Directional UWB Channel Characterization

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Abstract

In Ultra Wideband (UWB) wireless systems, multipath components have different waveforms depending on the used antennas and the angles of transmission and reception. Multi-template subtractive deconvolution is modified and applied to an extensive channel measurement campaign. The modified algorithm utilizes the variation on the waveforms to extract the directional UWB channel response. Directional characterization of UWB channels facilitates performance evaluation studies and allows for more accurate positioning and imaging. The use of subtractive deconvolution rather than zero-insertion used by previous authors allows for resolving overlapping components and hence improves the energy capture in Rake receivers.

I. INTRODUCTION

Ultra Wideband (UWB) technology is a potential candidate for short-range multiple access wireless communications and high-resolution range measurements. The essential promises of UWB technology are high transmission rates, excellent wall penetration, and low power consumption. For the rapidly growing UWB technology, accurate directional modeling is vital for high performance receiver design and positioning applications.

Some potential UWB characterization research work on both deterministic and statistical modeling is summarized in [1]. The early characterization attempts reported in the literature extend the narrowband measurement scenarios to the UWB case. Both the approach and the results need to be verified. Many issues remain unresolved and hence more UWB propagation investigations are desirable. Directional multipath performance is among the priority issues that demand accurate investigation in order to formulate comprehensive and robust models.

For narrowband characterization, usually no deconvolution is needed and the received signal can approximate the impulse response. Deconvolution was only used when super-resolutions were required [2]-[3]. Deconvolution is most needed for the characterization of wideband devices and channels due to the limited bandwidths of available test signals compared to the bandwidths of devices and channels themselves [4]. Since the channel under study is wideband, deconvolution techniques are needed to estimate the UWB channel impulse response. Moreover, with deconvolution the estimated channel impulse response is independent of the excitation signal, which allows for the simulation of different waveforms for wave-shaping studies.

Most of the existing UWB studies concentrate on the temporal behavior of the multipath components. Since the radiation pattern of the antenna vary with frequency, UWB multipath components transmitted and received at different angels will have different shapes. Usually directional channel characterization requires antenna arrays. This research proposes to utilize the diversity on the waveforms to extract the relative direction of arrival with single antenna. . Multi-template subtractive deconvolution is proposed to utilize the variation on the waveforms to extract the directional UWB channel response.

In the next section, data used for characterization are discussed. In section 3, the modified multi-template deconvolution algorithm is formalized. Directional information about the channel is extracted in section 4. Finally, some conclusions are extracted.

II. MEASUREMENT & DATA

UWB channels were measured in time domain by sounding the channel with pulses to obtain the impulse response. The setup used consists of a pulse generator that sends impulses to a TEM horn transmitting antenna through a balun. The received signal is observed using a digitizing oscilloscope. The receiver antenna is also a TEM horn connected to the test set through a balun. The 3 dB bandwidth for the pair of antennas is 1–7 GHz. The sampling oscilloscope is

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connected to a data acquisition unit. Synchronization is achieved through an external circuit.

The measurements were carried out in two buildings on Virginia Tech Campus. The first building comprised mainly of offices and classrooms with most walls made of drywalls with metallic studs. Some walls at certain locations including stairwells are made of cinderblock and poured concrete. The second building has interior walls, which are mainly made of drywalls and cinderblocks. The floor is covered with carpet inside the rooms and with tiles in hallways.

A total of 186 multipath profiles are examined. None-line-of-sight (NLOS) comprised 61 profiles. The remaining 125 profiles are LOS profiles. Every profile extends for 150 ns with 10 ps sampling interval. The pulse generator provides Gaussian-like pulses with FWHM (full-width half-maximum) duration of 85 ps. More details about the measurements and data acquisition can be found in [1]. Figure 1 depicts a 10 ns representative received multipath profile in the line-of-sight configuration.

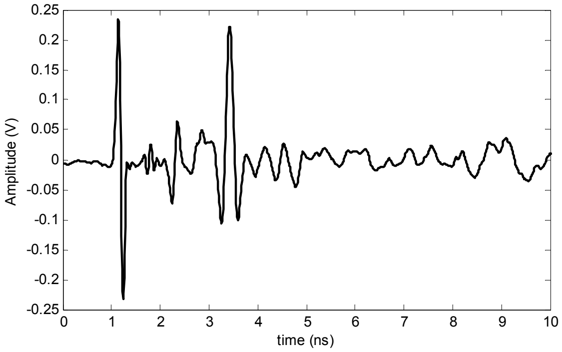

Figure 1. Typical received line-of-sight multipath profile

III. DECONVOLUTION TECHNIQUES

Channels can be characterized by their transfer function in the frequency domain or by their impulse response in the time domain. The measurements under investigation are represented in time domain. Deconvolution of the time-domain waveforms can be used to determine the impulse response of a linear time-invariant system.

Though, the transfer function and the impulse response give full channel description, only few parameters can be used by the receiver for channel estimation. Model deconvolution is usually used to characterize the channel with few parameters [5].

A. Model Deconvolution

The impulse response of the narrowband propagation channel is often modeled as a summation of delayed and scaled multipath components,

$$h(t) = \sum_{i}^{I} a_i \delta(t - \tau_i) \tag{1}$$

where a_i are the magnitudes of I multipath components. This model does not fit the UWB channel because the delta function at the receiver implies a wide channel bandwidth relative to the bandwidth of the excitation pulse. The sounding pulse, transmitter and receiver antennas, and the impulse response of the detector must be deconvolved form the received profile [6].

Since the transmitter and the receiver antennas do not have spherical patterns at all frequencies, the waveforms radiated/received in different directions from the transmitter antenna look different. For the measurements in hand, the waveforms received at different angles, look considerably different. Figure 2 illustrates a simple scenario where the transmitter and the receiver are facing each other and the receiver elevation angle is rotated in 15° steps. Due to the symmetry of the antenna, positive and negative angles result in the same pulse shape. The next subsection the model is modified to account for the variation on the received waveforms.

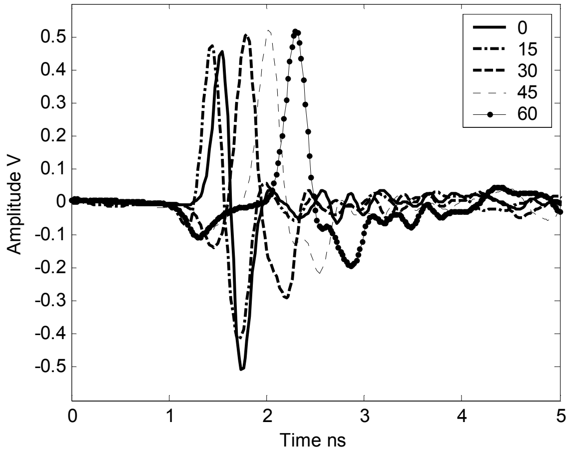

Figure 2. Received waveforms at different receiver elevation angles

B. Multi-Template Subtractive Deconvolution

Since received profiles are composed of different pulses, a modified channel model was suggested in [6]. The modified channel model is antenna specific and is given by

$$h(t) = \sum_{i}^{I} a_i \tilde{h}^j (t - \tau_i) \tag{2}$$

where $\tilde{h}^j$ is the impulse response of the j^{th} multipath component. Subtractive deconvolution is used to extract the model parameters where the amplitude, delay, and template shape for the strongest multipath components are estimated. Based on the estimated parameters the detected component will be subtracted from the received profile, $r(t)$, the reminder is known as the dirty map, $d(t)$. The process will continue to build a clean impulse response, $c(t)$, and a clean profile, $rc\ (t)$ which is made of delayed and scaled versions of the expected templates. The methodology for performing the deconvolution process depends mainly on the objective of the deconvolution process and the judgment criteria.

In channel characterization, our goal is to find the "best" values for the amplitude, delay and template shape (angles) such that the synthesized waveform is well matched to the received waveform. The extent of achieving the goal is measured using the energy capture. Energy capture, EC, is defined to be [7]

$$EC\,(L_p) = \left\{ 1 - \frac{\left\| r(t) - rc(t) \right\|^2}{\left\| r(t) \right\|^2} \right\} \times 100\% \tag{3}$$

where L_p is the number of single path correlators required in UWB Rake receiver to construct a filter matched to the received waveform so that the constructed waveform "adequately" captured the averaged received signal energy.

Assuming k different templates, the subtractive deconvolution algorithm is modified from that described in [2,6] as follows:

1) initialize the dirty map with the received waveform $r(t)$ $d(t)=r(t)$ and the clean map with $c(t)=0$;
2) form the correlation coefficient functions $\Gamma^j(\tau) = \tilde{p}^j(t)\Theta d(t)$, (normalization is understood and Θ means correlation), for $j=1,2,\ldots k;$
3) find the peaks (max Γ_i^j, $j=1,2,...k$), and their positions, τ_i, in the $\Gamma^j(\tau)$;
4) if all $\Gamma_i^j <$ threshold, go to step 8;
5) clean the dirty map by $d(t) - \Gamma_i^j \tilde{p}^j(t-\tau_i)$;
6) update the clean map by using $c(\tau) = c(\tau) + \Gamma_i^j h^j(t-\tau_i)$.
7) go to step 2;
8) the impulse response is then $\hat{h}(t) = c(t)$.

Note that in *step* (5), updating the dirty map was done in [6] and the subsequent researcher [8]-[9] by inserting zeros in place of the detected component rather than updating by replacing *d(t)* with $d(t) - \Gamma_i^j \tilde{p}^j(t-\tau_i)$. Inserting zeros inherently assumes that multipath components do not overlap. When examining large number of profiles, one concludes that many multipath component overlap to produce a new shape, which is the superposition of the overlapping components. The idea is illustrated in Figure 3a with a profile measured in a corridor with scatterers (walls) at similar distances from the antennas. Using 20 templates, the reconstructed profiles with zero-insertion and using subtractive multi-templates deconvolution are shown in Figures 3b, and 3c respectively. Comparing the two figures with the measured profile it is evident that subtractive deconvolution performs better.

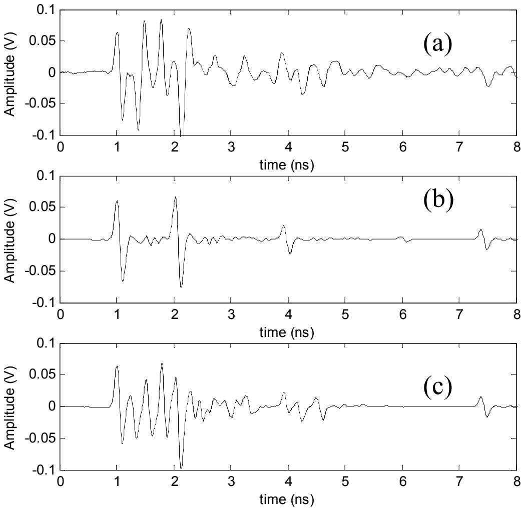

Figure 3. (a) Received profile, (b)reconstructed with zero-insertion, (c) reconstructed with subtractive deconvolution

Figure 4 further clarifies the concept. Zero-insertion has limited energy capture while subtractive deconvolution increases monotonically as a function of the recovered templates. The zero-insertion might be justified in very dispersive channels because subtracting the template from the dispersed received profile results in a large remainder. This reminder might be mistakenly identified as "phantom" multipath component. On the other hand, zero-insertion in addition to missing true multipath components could results in "phantom" components around the previously detected components. Counting the numbers of multipath components is not an objective by itself.

The templates to be deconvolved are waveforms received at different angles. The templates can be measured in an open environment with time gating no anechoic chamber is not required. This allows for directional channel characterization. Other templates can be selected for optimizing the energy capture.

The authors in [8] have taken into account the distortion of pulse shape introduced by propagation process. They used a single reference measurement in a real measurement environment. Templates were obtained manually to optimize the captured energy. This process is claimed to eliminate the "phantom paths". This choice is not appropriate for our directional characterization and does not reflect physical parameters.

The deconvolution process can be terminated if certain energy percentage is achieved or when the increment on the captured energy is below a certain threshold. Termination criteria can also be a certain number of multipath components or a specific path amplitude threshold.

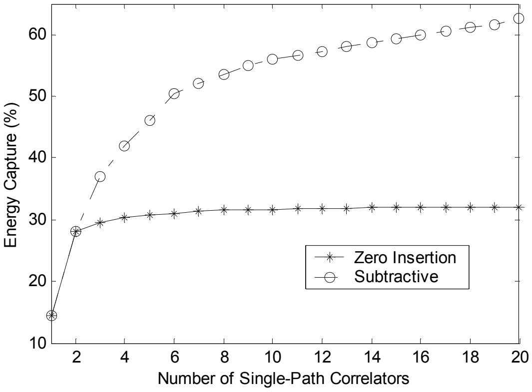

Figure 4. Energy capture using zero-insertion and subtractive deconvolution

In the next section, the multi-template subtractive deconvolution is applied to the available data with different number of templates.

IV. RESULTS & ANALYSIS

The energy in the measured multipath profiles is now captured using correlators with a fixed template and compared with that obtained using the proposed subtractive multi-template correlators. For the multi-template case, the reference templates are based on antenna measurements at different elevation angles. Since usually a finite number of dominant multipath components exist in a typical received waveform. We used 20 multipath components in every profile.

Figure 5 depicts the improvement in the captured energy versus the number of captured multipath components. NLOS and LOS scenarios are presented separately. For each of the LOS and NLOS scenarios, the captured energy is shown using single template and using the five suggested templates. For the case of single template, the reference template was measured at 0^o. For the case of five reference templates, the measurements were performed at the following set of elevation angles (0^o,15^o,30^o, 45^o, 60^o).

In both LOS and NLOS cases, using five templates resulted in about 11% increase in the captured energy. For LOS scenarios, the performance saturated with single and five templates at about 70% and 82% of the received energy, respectively. For NLOS scenarios, it is 57% and 67% for single and five templates, respectively.

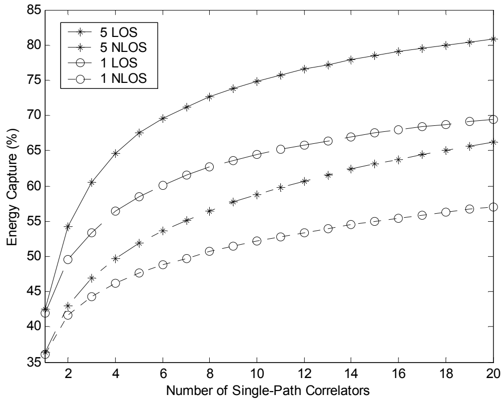

Figure 5. Energy capture for different number of reference templates

Figure 6 illustrates the directional distribution of the received templates. The figure illustrate relatively high occurrence for the 60^o.

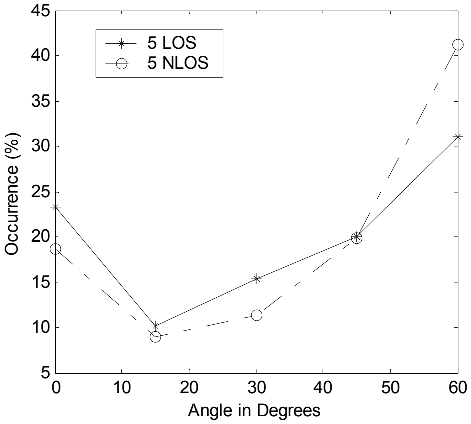

Figure 6. Extracted angle distribution for LOS and NLOS scenarios

It is worth to note that all arrivals with angles beyond 60 have the highest correlation with 60^o templates. It was also noted in [9] that selecting the template form a typical received profile or even using noise and random templates results in good energy capture. This can be explained by noting that the aggregate effect of propagation is low pass filtering and the delayed components will have more low frequency components compared to the first few arrivals. The lowpass filtering results in expanding the pulse with time and hence the energy is distributed evenly through time and can be evenly captured using random pulse shapes. Waveforms received at higher angles suffer from the same lowpass filtering effect due to the characteristics of the antenna.

V. CONCLUSION

In this paper, a directional multi-template subtractive deconvolution was proposed and applied to an extensive UWB measurement campaign. The resultant impulse response is directional. It shown that the captured energy increases by more than 10% when using five directional correlators rather than one. The use of subtractive deconvolution rather than zero-insertion used by previous authors allowed for resolving overlapping components and increased the captured energy. Further extension of the work would include optimizing the choices of reference templates based on extensive antenna measurements.

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