Verifying the effectiveness of the stored channel simulation in evaluating UWB system performance

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Abstract

This paper describes the verification of the effectiveness of stored channel simulations for evaluating ultrawideband (UWB) communication system performances in realistic propagation environments. It was achieved by investigating the similarity of two received waveforms: one acquired by the real signal transmission and the other reconstructed using stored channel simulation. The actual received waveform was directly measured by a UWB testbed. On the other hand, the transfer function of the antennas and propagation channels measured by a vector network analyzer, i.e. the stored channel, together with the transfer functions of the transmitter and receiver of UWB testbed, were used in simulation to reconstruct the received waveform. The result shows that the actual measured received waveform is almost identical to the reconstructed received waveform via stored channel simulation.

1. Introduction

Ultrawideband signals are defined as signals with either an absolute bandwidth larger than 500 MHz or a relative bandwidth larger than 20 %. This large bandwidth leads to new possibilities for both UWB radars and UWB communications applications from which UWB systems gain interest of researchers [1]. The standardization groups such as IEEE802.15.3a and IEEE802.15.4a for UWB communications systems have developed the channel models in order to compare standardization proposals for high data rate and low data rate wireless personal area networks (PANs) [2], [3] respectively. These standardized channel models are stochastic models based on probability theories and thus not available to evaluate the transmission in realistic environments. On the other hand, the stored channel, which is defined as the experimentally measured transfer function or impulse response, is often used to reflect the properties of propagation channels in a real environment for device testing [4]. We have been investigating how precisely the stored channel can describe the UWB system performance [5]. This paper shows the comparison of the actual received waveform measured by UWB testbed [6], which is developed by the National Institute of Information and Communications Technology (NICT) in Japan, and the received waveform obtained from stored channel simulation. If stored channel simulations in evaluating UWB transmission are proved to be efficient, they can replace the use of actual devices. As a result, the cost to make prototypes for transmission systems or design UWB wireless devices can be reduced.

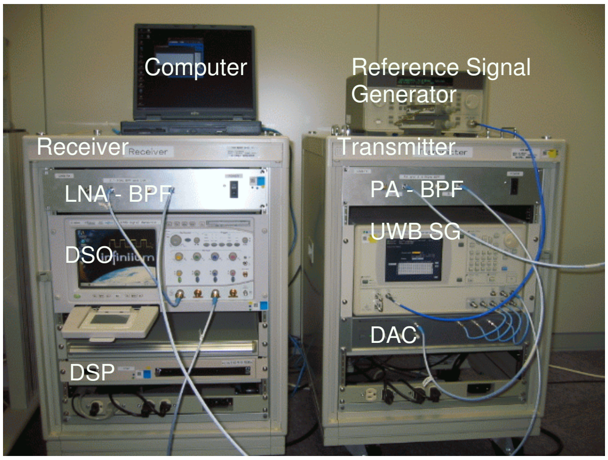

Fig. 1: The transmitter and receiver of UWB testbed

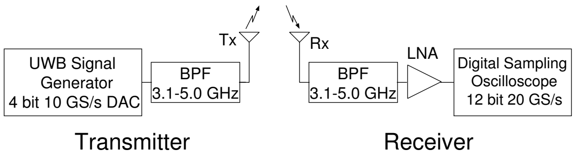

Fig. 2: Block diagram of UWB testbed

This paper is further divided into 4 sections: UWB testbed, experiment, result and discussion, and summary and conclusion. Section 2 briefly describes the UWB testbed used in this research. Section 3 describes the transmission experiment and the propagation experiment as well as how to reconstruct the received waveform. In section 4, the received waveforms from the two experiments are shown. Discussions on the results are also given. Finally, a summary and conclusion wraps up this paper.

Fig. 3: The environment of the measurement campaigns

TABLE 1: SPECIFICATIONS OF THE TRANSMISSION EXPERIMENT

Measurement equipment	UWB testbed
Pulse repetitive period of transmitted signals	128 ns
Sampling rate	100 ps
Peak voltage of transmitted signals	about 600 mV
Type of transmit and receive antennas	UWB monopole antenna [7]
Distance between antennas	1.2 m
Height of antennas	1.0 m
Number of averaging operations	1024 times

2. UWB TESTBED

The UWB testbed consists of a transmitter, a receiver, a reference signal generator and a computer as shown in Fig. 1. On the transmitter side, there are a UWB signal generator (UWB SG), a band-pass filter (BPF) and a power amplifier (PA). The receiver side comprises a BPF, a low-noise amplifier (LNA), a digital sampling oscilloscope (DSO) and a digital signal processor (DSP). The BPFs in the transmitter and receiver both have passbands of $3.1 - 5.0$ GHz. The reference signal generator provides an external trigger signal via a coaxial cable from the transmitter to the DSO. The computer is used to control the whole UWB testbed via LAN cable.

Figure 2 describes the composition of the UWB transmitter and receiver used in this research. On the transmitter side, the signal generator uses the 10 GS/s, 4-bit DA Converter (DAC) to generate the UWB signals up to 5 GHz. These signals are then sent to the transmit antenna after limiting the bandwidth to $3.1 - 5.0$ GHz using the BPF.

On the receiver side, the signal received from the receive antenna passes through the BPF to filter the out-band interference. They are then amplified by the LNA and finally detected at the 12 bits, 20 GS/s high-speed DSO.

3. EXPERIMENT

In this research, we conducted two experiments: transmission experiment and propagation experiment. Both experiments were carried out in the same propagation environment with the same antenna position. As can be seen in Fig. 3 and

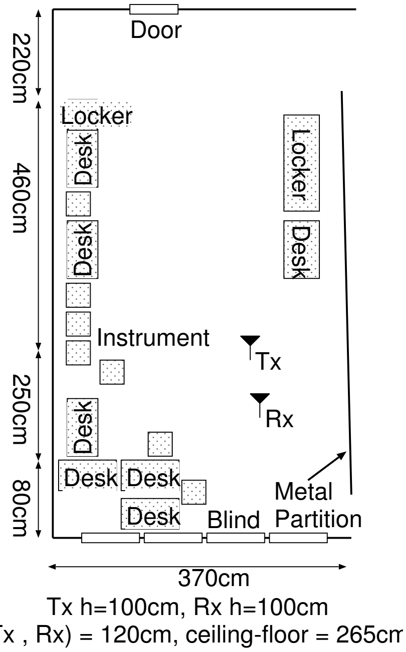

Fig. 4: Floor plan of the measurement campaigns in an indoor environment

TABLE 2: SPECIFICATIONS OF THE PROPAGATION EXPERIMENT

Measurement equipment	Vector Network Analyzer
Bandwidth	$3.1 - 5.0$ GHz
Frequency sampling interval	1.0 MHz
Emitted power	-17 dBm (sinusoidal wave)
Number of averaging operations	10 times

Fig. 4, there were numerous clutters such as metal partitions, desks, devices around the transmit and receive antennas. In other words, these experiments have been performed in a rich multipath environment.

The transmitted signal used in both experiments was the impulse response of a Root-Raised Cosine (RRC) filter modulated by a sinusoidal wave with frequency f_c. The time domain and frequency domain responses are mathematically written as [6]:

$$p(t) = \frac{\cos\frac{(1+\alpha)\pi t}{\tau} + \frac{\tau}{4\alpha t}\sin\frac{(1-\alpha)\pi t}{\tau}}{1-(\frac{\alpha t}{\tau})^2}\cos 2\pi f_c t \qquad (1)$$

where τ is the duration-determined parameter and α is the roll-off factor. We used $\alpha = 0.35$, $\tau = 0.75$ ns and pulse width $T_d = 4.8$ ns for the transmitted signal.

$$|P(f)| = \begin{cases} 1 & |f - f_c| \leq (1-\alpha)\omega_c \\ 0 & |f - f_c| \geq (1+\alpha)\omega_c \\ \sqrt{\frac{1+\cos\frac{\pi(\omega-\omega_c(1-\alpha))}{2\alpha\omega_c}}{2}} & \text{otherwise} \end{cases} \qquad (2)$$

In order to meet the UWB SG specification described in Section 2, this waveform was quantized into 4-bit, 10GS/s data. The continuous and quantized RRC transmitted signals

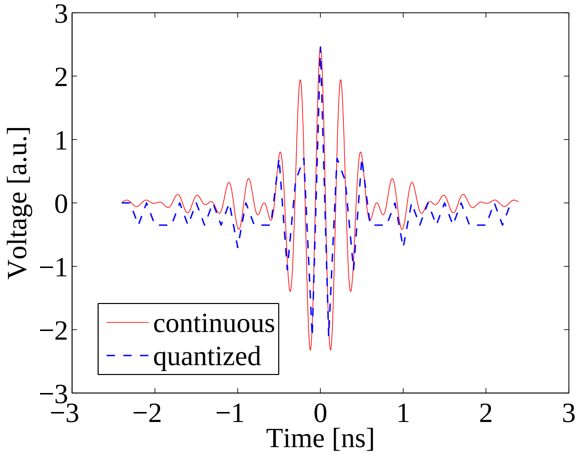

Fig. 5: Impulse response of transmitted signal

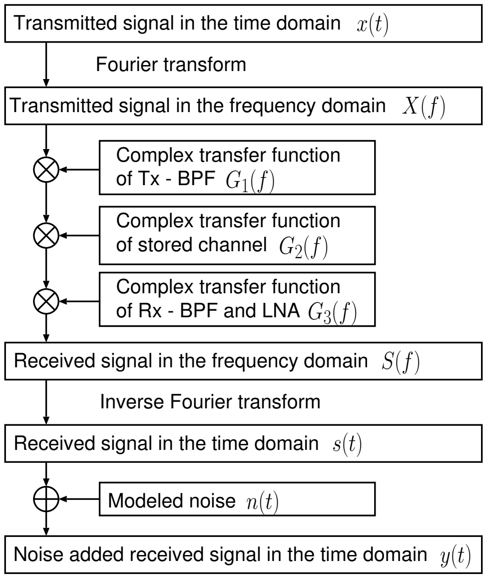

Fig. 7: Flow chart of received waveform simulations using a stored channel

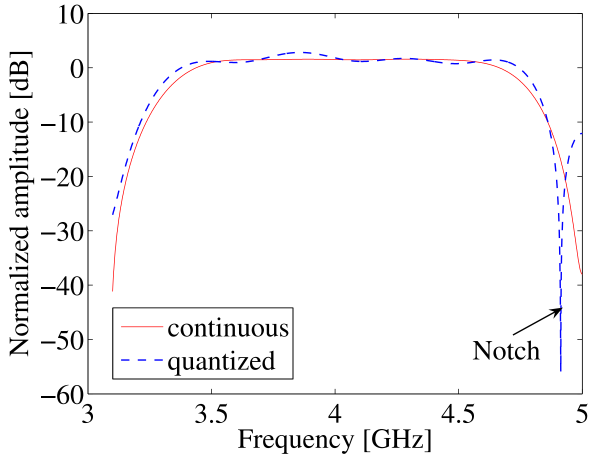

Fig. 6: Frequency response of transmitted signal

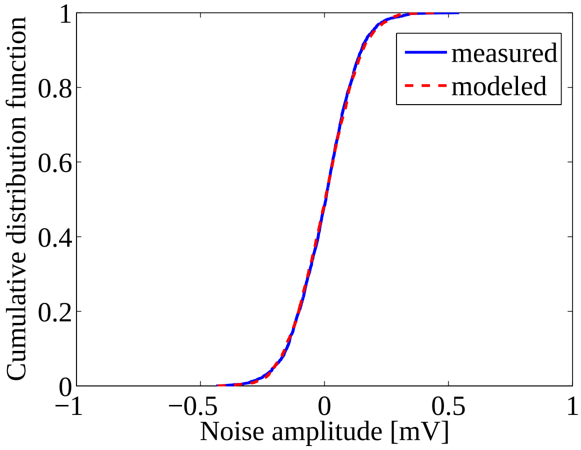

Fig. 8: Cumulative distribution functions of actual and modeled noise

in time and frequency domains are shown in Fig. 5 and Fig. 6, respectively. As expected, the frequency power spectrum of the quantized signal did not agree the continuous power spectrum completely, and a notch was found around 4.9 GHz.

A. Transmission experiment

The transmission experiment was conducted via the UWB testbed. The parameters used in this experiment are shown in Table 1. The averaging function of DSO was used in order to improve the signal-to-noise ratio (SNR) in the received waveform. Without averaging operations, it would have been extremely difficult to distinguish between the received signal and the noise. The SNR of the received waveform after averaging was 17.6 dB.

B. Propagation experiment

In order to obtain the received waveform via stored channel simulation to compare with the received waveform in UWB testbed, we used the VNA to measure the transfer function $G_2(f)$ of the propagation channels including both transmit and receive antennas. The transfer functions $G_1(f)$ of BPF on the transmitter side and $G_3(f)$ of BPF and LNA on the receiver side of UWB testbed were also measured with the VNA. Table 2 shows the parameters of the VNA in the measurement.

The measured transfer functions were then used to reconstruct the received waveform as described in the flow chart in Fig. 7. First, the transmitted signal in the time domain $x(t)$ was transformed into the frequency domain using discrete Fourier

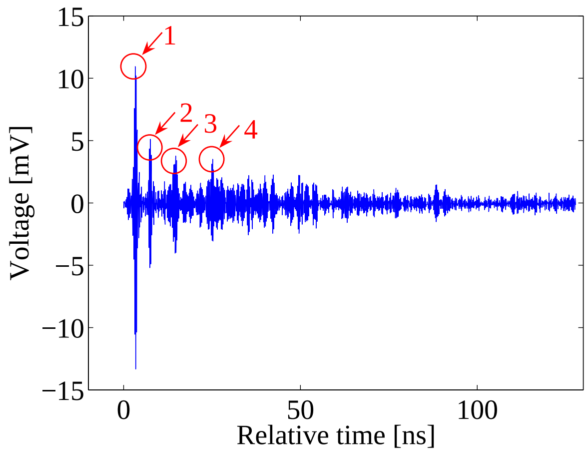

Fig. 9: Received waveform by actual measurement

transform (DFT).

$$X(f_k) = \sum_{m=0}^{M-1} x(t_n)\mathrm{e}^{-\jmath 2\pi t_m f_k} \tag{3}$$

Then, the received signal in the frequency domain $S(f_k)$ was calculated as

$$S(f_k) = X(f_k)G_1(f_k)G_2(f_k)G_3(f_k) \tag{4}$$

After that, we applied the inverse discrete Fourier transform (IDFT) to acquire the received signal in the time domain.

$$s(t_m) = \frac{1}{K}\sum_{k=0}^{K-1} S(f_k)\mathrm{e}^{\jmath 2\pi f_k t_m} \tag{5}$$

This received signal was noise-free, whereas the actual measured received waveform was distorted by the internal DSO noise and other interference signals. Therefore, it was necessary to model this noise and add to the noise-free received signal as shown in the following equation.

$$y(t_m) = s(t_m) + n(t_m) \tag{6}$$

Modeling the noise and interference signals was performed using the measured data from the DSO. During the measurement, there was no signal transmitted from UWB testbed. The measured noise including interference signals was supposed to be white gaussian because it was measured using DSO over a long period with the averaging operations. Therefore, we created the modeled noise $n(t)$ as white gaussian noise with the same mean ($\mu = 0.00$ mV) and standard deviation ($\sigma = 0.12$ mV) as the measured noise. Figure 8 shows the cumulative distribution functions of the measured and modeled noise.

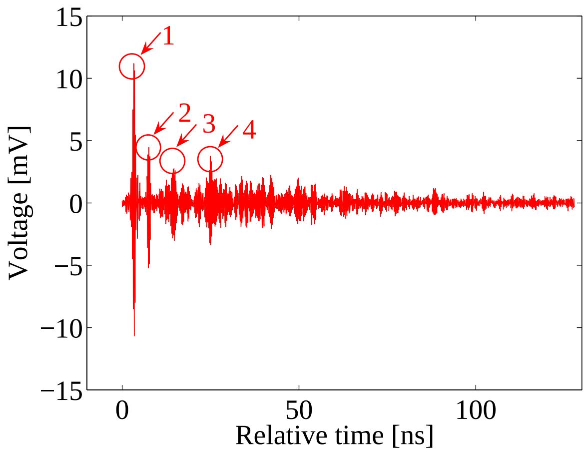

Fig. 10: Received waveform obtained by stored channel simulations

TABLE 3: COMPARISON OF LOCAL PEAKS OF RECEIVED WAVEFORMS OBTAINED BY ACTUAL MEASUREMENT AND STORED CHANNEL SIMULATIONS

	V_1 [mV]	V_2 [mV]	V_3 [mV]	V_4 [mV]
Actual measurement	10.95	5.11	3.76	3.51
Stored channel simulations	11.18	4.45	2.75	3.75

4. RESULT AND DISCUSSION

The received waveforms in actual measurement and reconstructed in simulation were compared to verify the effectiveness of stored channel simulations.

The waveform obtained from the transmission experiment and reconstructed waveform via stored channel simulations are shown in Fig. 9 and Fig. 10, respectively.

Comparison of two waveforms revealed that multipath signals appeared at the same delayed time compared to the direct signal in both waveforms. In addition, focusing on the four strongest waves, it was found that wave 1 was the direct wave and wave 2, 3, 4 were the reflected waves with the delayed time of 4.3, 11.4, 21.7 [ns] respectively. These reflected waves were probably due to reflection from the metal partition on the right of the antennas and the metal clutters on the left of the antennas shown in Fig. 3. However, it was impossible to determine the exact trace of propagation paths because angular information of waves was not available. As shown in Table 3, the peak amplitude values in two received waveforms was almost the same. Finally, the correlation of this two waveforms was 0.87, which proved that the received waveform obtained from actual measurement was nearly identical to the one obtained from stored channel simulations.

5. SUMMARY AND CONCLUSION

In this paper, we have investigated the effectiveness of stored channel simulation, which was used to evaluate the transmission characteristics of UWB communications systems in realistic environments. We performed the comparison of the actual measured and the simulated received waveforms. The result proved that the received waveform obtained from actual measurement using UWB testbed was nearly identical to the reconstructed received waveform via stored channel simulation. In our experiment, high power was radiated under the approved radio license to assure sufficiently high SNR on the receiver side. However, this radiated power level was much higher than which is defined in the FCC spectrum mask. In other words, high SNR is hard to be realized on the receiving side when implementing realistic UWB applications. Thus the stored channel simulations should also be evaluated with lower radiation power which satisfies the FCC mask. In such a case, bit error rate (BER) is a good measure. Therefore, we will perform the comparison of BER from the UWB testbed and stored channel simulations.

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