Beamforming for Impulse-Radio UWB Communication Systems Based on Complex-Valued Spatio-Temporal Neural Networks

Hayato Yoshida #1, Akira Hirose ##2

Department of Bioengineering, The University of Tokyo
Department of Electrical Engineering and Information Systems, The University of Tokyo
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan
[1] h_yoshida@eis.t.u-tokyo.ac.jp
[2] ahirose@ee.t.u-tokyo.ac.jp

***Abstract*—Ultra-wideband (UWB) wireless communications based on impulse radio uses so short pulses that its occupied bandwidth is very large and the density of spectral power is low. Then, UWB has high confidentiality and low interference to other narrowband wireless communications. However, in the situation of multiple access and fixed transmission-speed, communication quality of UWB becomes low by interference from other UWB nodes. In high-speed UWB communications, where symbol period is short and pulse density is high, the communication quality of UWB is also low by multipath interference. In this paper, we reduce the degradation of communication quality by using a complex-valued spatio-temporal neural network beamformer (CVST-NN-BF).We evaluate bit error rate (BER) of UWB wireless communications based on impulse radio in multipath environment.**

I. Introduction

In multiple access and fixed transmission-speed situation, communication quality of ultra-wideband (UWB) wireless communications based on impulse radio often becomes very low because of the interference from other UWB nodes. It also becomes further low with multipath interference waves delayed larger than its symbol period. In high-speed communications, e.g., with 1 Gbps bit rate, degradation by the multipath interference is large. However, we can suppress such interference from other nodes and multipaths by using beamforming.

In conventional beamfomer for narrowband communications, its radiation pattern depends only on the number of antennas and the operation frequency. In the UWB communications, however, it cannot realize sharp selection in space [1]. Hum et al. proposed a UWB beamformer based on infinite-impulse-response two-dimensional (IIR-2D) frequency-planar beam space-time plane wave filter [2] [3]. Widrow et al. proposed another filter with tapped-delay-line (TDL) structure [4]. However, Widrow's broadband beamformer treats only real part of the signals. On the other hand, Suksmono and Hirose proposed complex-valued spatio-temporal neural-network beamformer (CVST-NN-BF) which deals with analytical signals [5].

In both the Widrow and Suksmono cases, a beamformer requires learning. In a communication system, it learns the best processing by using a set of teacher signals in the preamble. In this paper, we propose a learning process and evaluate the bit-error rate (BER) of an UWB system based on impulse radio.

The rest of the paper is organized as follows. Section II describes the spatio-temporal processing in construction of the CVST-NN-BF system and its operation including the learning process. Section III shows the results of simulations in multipath interference. Discussion is given in Section IV. The paper is concluded in Section V.

II. CVST-NN-BF for UWB wireless communication based on impulse radio

Our goal is to reduce degradation of communication quality which is caused by interference from other nodes and multipaths in high speed UWB by using the CVST-NN-BF. The construction of the CVST-NN-BF is represented in Fig.1.

Signals received in each antenna are Hilbert-transformed to yield analytical signals. Then they are input to a set of TDLs where the time-sequential input signals are developed in space. We denote the analytical signal which is from ith antenna and passing through mth delay tap at n desecrate time which is expressed as

$$x_{im}(n) = |x_{im}(n)| \exp(j\theta_{im}(n)) \quad (1)$$

Figure 2(a) shows the symbol for the TDL, while Fig.2(b) presents the circuit in a TDL. In the TDL, the complex-amplitude signals weighted and summed. In addition, outputs of each TDL are summed to yield a total summation u. Then u is fed to the activation function f to generate an output of

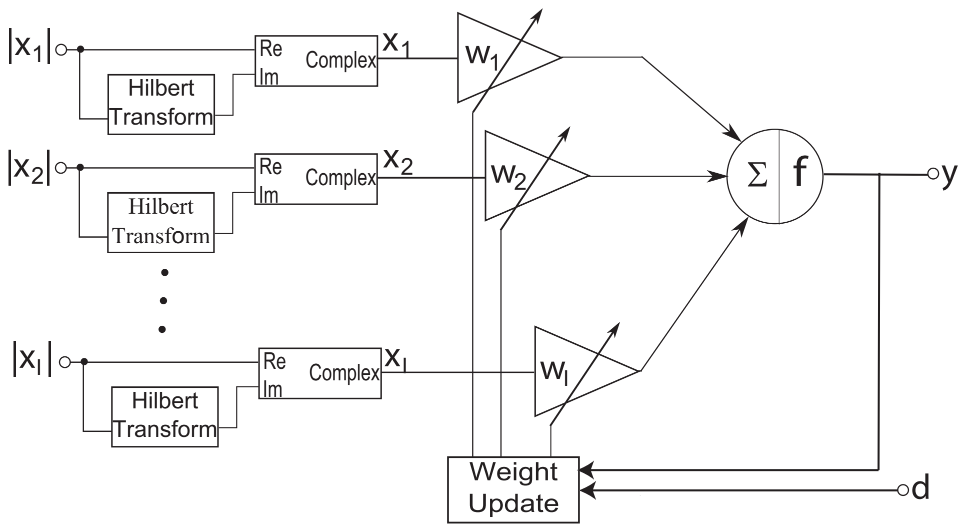
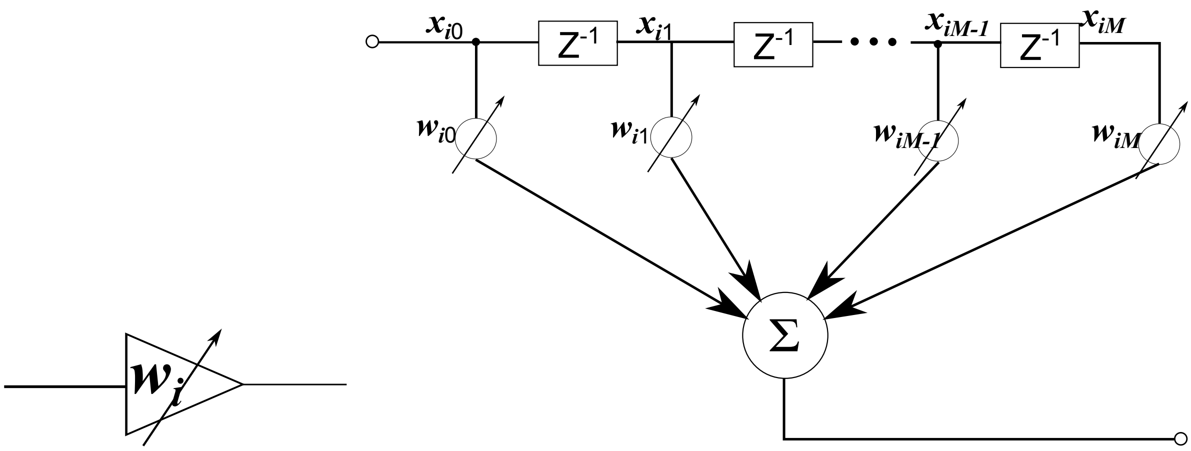


Fig. 1. Block diagram of the complex-valued spatio-temporal neural network for ultra-wideband beamforming



(a) (b)

Fig. 2. Tapped Delay Line (TDL)

the CVST-NN y as

$$u = \sum_{i=0}^{I}\sum_{m=0}^{M} w_{im}x_{im} \tag{2}$$

$$\begin{aligned} y &= |y|\exp(j\arg(\theta)) \\ &= f(u) \\ &= \tanh(|u|)\exp(j\arg(u)) \end{aligned} \tag{3}$$

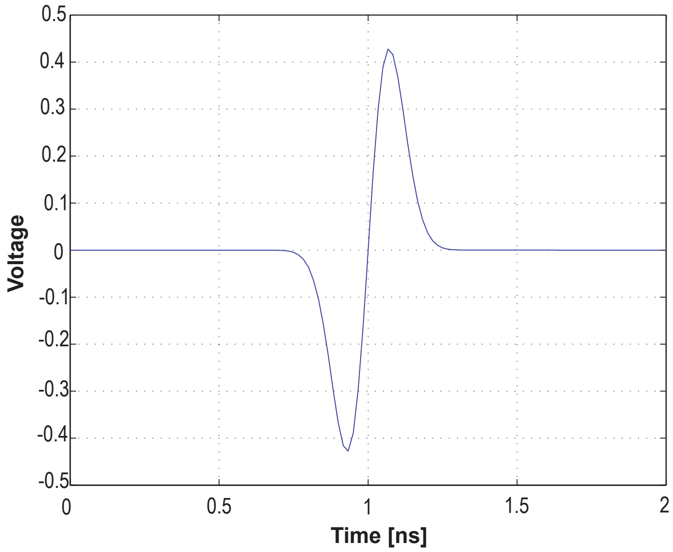
The error between the teacher signal and the output of the CVST-NN updates neural weights w_{im} for x_{im} as

$$\begin{aligned} &|w_{im}(n+1)| \\ &= |w_{im}|(n) \\ &- K\big\{(1-|y|^2)(|y|-|d|\cos(\theta-\theta_d))|x_{im}|\cos(\theta_{im}^{rot}) \\ &- |y||d|\sin(\theta-\theta_d)\frac{|x_{im}|}{|u|}\sin(\theta_{im}^{rot}))\big\} \end{aligned} \tag{4}$$

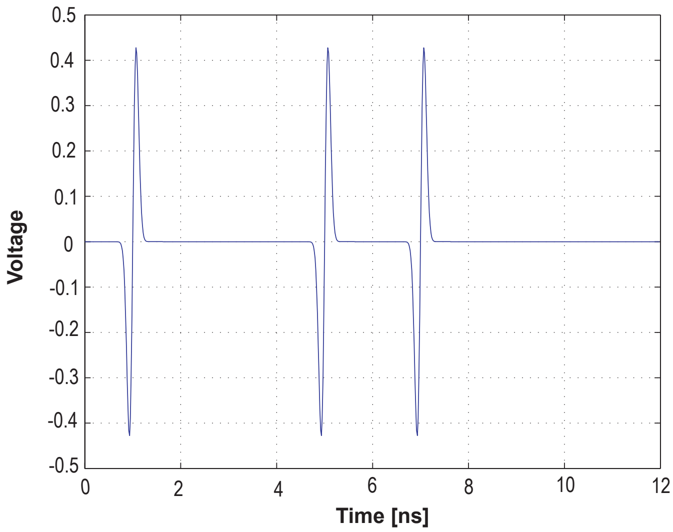
$$\begin{aligned} &\arg(w_{im})(n+1) \\ &= \arg(w_{im}(n)) \\ &- K\big\{(1-|y|^2)(|y|-|d|\cos(\theta-\theta_d))|x_{im}|\sin(\theta_{im}^{rot}) \\ &+ |y||d|\sin(\theta-\theta_d)\frac{|x_{im}|}{|u|}\cos(\theta_{im}^{rot})\big\} \end{aligned} \tag{5}$$

$$\theta_{im}^{\mathrm{rot}} = \theta - \theta_{im} - \arg(w_{im}) \tag{6}$$

The CVST-NN receiver uses a series of preamble signals known to both of transmitter and receiver as a set of teacher signals for the learning process. The preamble length should be sufficiently long for convergence of the error between the teacher signal and the output of the CVST-NN. The preamble signals consist of a repeated series of symbols so that the CVST-NN can learn the input-output relationship efficiently.



(a) Monocycle pulse



(b) A repeated series of pulses for a teacher signal

Fig. 3. Pulse shapes

III. Result of simulations

In this paper, we evaluate BER of a UWB system based on impulse radio using the CVST-NN-BF, Widrow's Broadband-BF, and the conventional delay and sum (DAS) narrowband beamfomer respectively in multipath environment by simulation. The pulse used in the simulation is monocycle as shown and in Fig.3(a). Its center frequency $f_c = 1$ GHz. Sampling frequency is 60 GHz. The number of antenna $I = 5$. We place antennas as a line array. Its interval length is 0.5λ ($\lambda = c/f_c$, c = velocity of light). The TDL consists of 128 taps. Desired signals come from 0°, and multipath signals come from 4 ° with a delay of 2ns.

We emplot 100% amplitude modulation. When a pulse exits in a time slot, it means 1. When pulse doesn't exit, it means 0. Then the information per symbol is 1 bit. Transmission-speed is 500 Mbps, resulting in a symbol period of 2ns. A repeated series of pulses for a teacher signal is expressed in Fig. 3(b). After learning 1,000 symbols (=2μs), the CVST-NN-BF receives 100,000 random symbols (payload). The BER of is shown in Fig. 5.

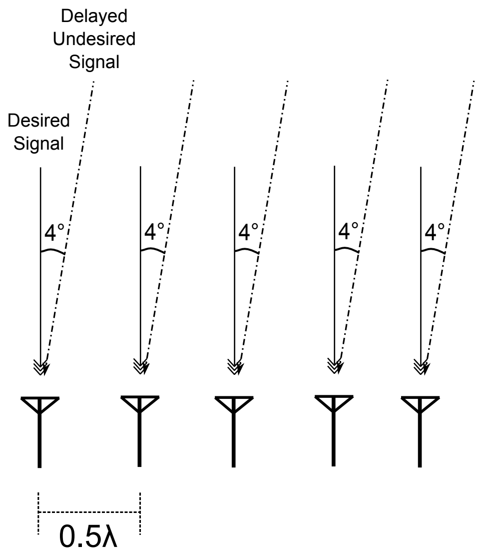


Fig. 4. Asummed environment in simulation

IV. Discussion

Fig. 5 shows that the BER of the CVST-NN-BF is higher than that of the DAS when the signal-to-noise ratio (SNR) is lower than 8dB. Similarly, the BER of Widrow's broadband BF is higher than that of DAS when the SNR is lower than 12dB. In this low SNR region, the learning is affected by the additive white Gaussian noise (AWGN). On the contrary, when the SNR is higher than 8dB, the BER of the CVST-NN-BF is lower than that of the DAS. When the SNR is higher than 12dB, the BER of Widrow's broadband BF is also lower than that of the DAS. In these high SNR region, the learning is completed successfully, and the multipath interference is a bigger factor of the degradation than the AWGN. The BER of the CVST-NN-BF is 1.5dB better than that of Widrow's broadband-BF at BER = 10^{-3}, and is 2.5dB better than that of DAS at BER = 2×10^{-5}.

V. Conclusion

Impulse-radio UWB systems are expected to realize a high-speed low-interference communications. In this paper, we evaluated the performance of the complex-valued spatio-temporal neural-network beamformer (CVST-NN-BF) in a UWB wireless communication system where the delayed multipath interference is the main factor of the degradation of communication quality. Simulation results showed that the CVST-NN-BF is 2.5dB better than the conventional delay and sum (DAS) and 1.5dB better than Widrow's broadband BF.

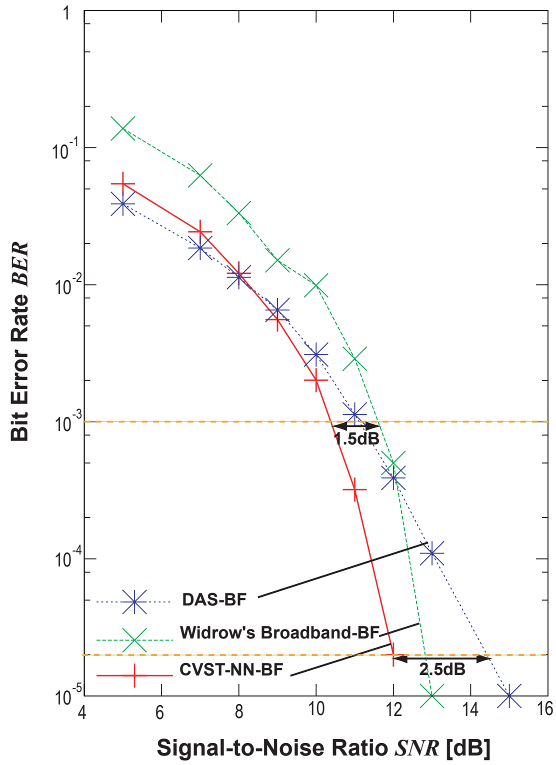


Fig. 5. BER of an UWB system based on impulse radio using CVST-NN-BF, Widrow's Broadband-BF, and delay and sum (DAS) narrowband beamfomer in multipath environment

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