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A Spatio-Temporal Equalization Method with Beamforming Criterion Selectability

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Summary
This paper proposes a spatio-temporal equalization method, which employs a cascade configuration of an adaptive array and a decision feedback equalizer (DFE). With the configuration, the proposed equalizer requires small number of weights, and hence, low computational complexity, however, it has to pay a price for the simplicity, namely, noise enhancement due to high sidelobe levels in certain radio propagation environments. In this paper, we settle the problem by introducing beamforming criterion selectability. The proposed equalizer changes a criterion in spatial weight calculation depending on channel condition, therefore, it can achieve good performance even in the channel models where directions of arrival (DoAs) of incoming waves are randomly determined. This paper investigates the bit error rate (BER) performance of the proposed equalizer in the channel models, which are based on measurement reports, in comparison with adaptive tapped-delay-line (TDL) arrays.

Key words:
Adaptive arrays, Decision feedback equalizers, Array signal processing, wireless LAN

1.Introduction

Spatio-temporal equalization, which utilizes both spatial and temporal information of received signal, has been drawing much attention as an essential technique to support multimedia services in wireless communications systems. Numerous studies have been made on spatio-temporal equalization in order to achieve good performance, and a lot of the equalization methods have been proposed [1]-[4]. However, though the methods can achieve good performance, real time processing could be hardly possible in high speed communications systems, such as broadband wireless LANs, since those methods employ the configuration of the adaptive TDL array (ATDLA)(Fig.1) or maximum likelihood sequence estimation (MLSE) approach in the weights calculation, which result in high computational complexity.

We have been proposing spatio-temporal equalization methods [5]-[7], which utilizes a cascade configuration, such that an adaptive antenna array is followed by a DFE (Fig.2). The cascade configuration requires small number of weights, and hence, less computational complexity than the ATDLA based spatio-temporal equalizer. However, the cascade configuration has to pay a price for the simplicity. When DoA of a desired wave is almost the same as that of an undesired wave, SNR (Signal to Noise Ratio) of the received signal could be degraded, because of high sidelobe levels and spatial whiteness of the noise, and it is difficult to improve the performance with the temporal processing in the latter part. In this paper, we settle the problem by introducing **beamforming criterion selectability**. Owing to the selectability, the proposed equalizer can achieve good performance even in the channel models where DoAs of incoming waves are randomly determined. We also show the BER performance of the proposed equalizer in the channel models, which are based on measurement reports [8],[9], and compare the performance between the ATDLA and the proposed spatio-temporal equalizer.

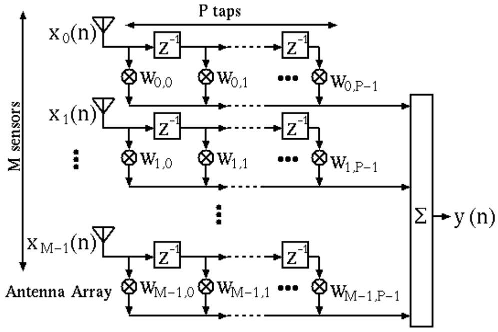

Figure 1- Adaptive TDL Array

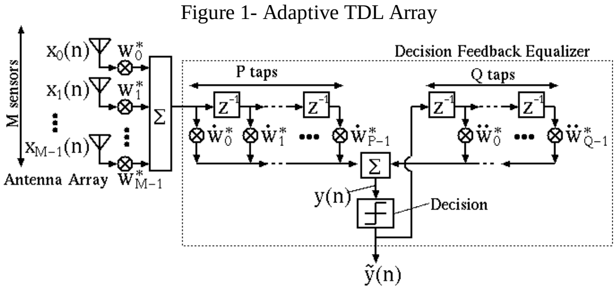

Figure 2- Cascade Configuration

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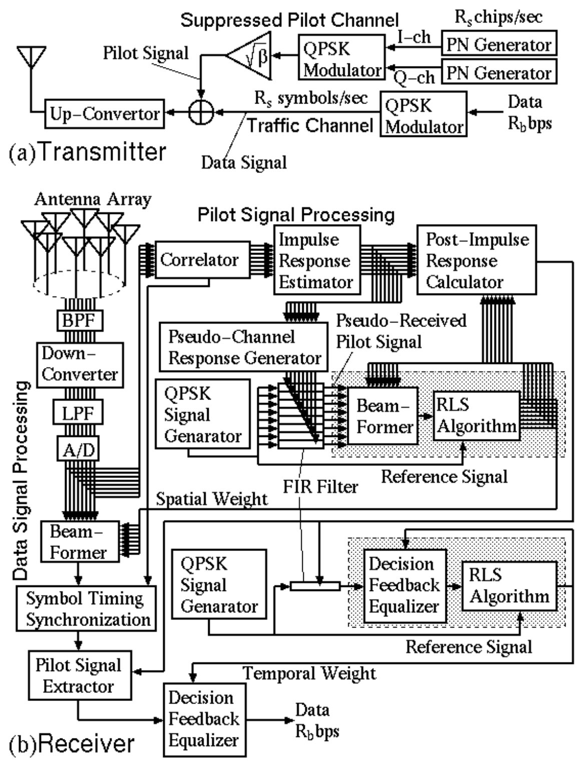

Figure 3-System Configuration

2. System Configuration

Assume that the proposed spatio-temporal equalizer is applied to the downlink of a 60 GHz indoor wireless LAN. Fig.3 shows the transmitter and receiver structure. In our method, we prepare two types of channels; a traffic channel and a pilot channel. The traffic channel is used to convey information signals, and the pilot channel is for the pilot signal, which is used to estimate the channel impulse response.

In the receiver, the incoming waves are received by an antenna array. After then, the received signal is processed in the data signal processing section and in the pilot signal processing section independently. In the data signal processing section, the outputs from the matched filters are multiplied by the weights of the beamformer, which are calculated in the pilot signal processing section. After symbol timing synchronization, pilot signal extraction and equalization with the DFE, the data are recovered.

In the pilot signal processing section, the complex instantaneous channel impulse response at each sensor is first estimated by correlating the received pilot signal. Then, using the estimated channel impulse response, the receiver selects a suitable beamforming criterion for the channel condition. In our method, the equalizer calculates the weights of beamformer using the pseudo-received pilot signal which is generated in the receiver, and the equalizer can change its beamforming criterion by selecting an appropriate impulse response for the pseudo-received pilot signal generation. Details of the selection of beamforming criterion, in other words, impulse response for the pseudo-received pilot signal generation, are discussed in section 3. The weights of the beamformer are calculated by the recursive least square (RLS) algorithm with the pseudo-received pilot signal. The weights of the DFE are also determined in the same manner as the beam-weight calculation using the pseudo-received pilot signal, which is generated from the estimated channel response including the beamformer.

3. Beamforming Criterion Selection

We show the classification of the channel conditions, and discuss suitable beamforming criterion for the each channel condition.

- *Small Angular Spread of Each Incoming Wave*
  In this case, DoAs of incoming waves can be estimated from phase differences of the estimated channel response. According to DoA patterns, the channel conditions can be further classified into the following two situations;
  - *DoA of the desired wave ≠ DoA of the undesired wave*
    The adaptive array can capture only the desired wave (the path with the maximum power), therefore, the equalizer utilizes **the estimated channel response as it is** (*Response 1*) for the pseudo-received pilot signal generation.
  - *DoA of the desired wave ≈ DoA of the undesired wave*
    The equalizer utilizes **the estimated channel response without the undesired component** (*Response 2*), in order to capture both the desired and the undesired waves.
- *Large Angular Spread of Each Incoming Wave*
  In this case, DoAs of incoming waves cannot be estimated from the channel impulse response, however, the adaptive array operates as a diversity system because of low correlation of the received signals among the sensors. Therefore, the equalizer can select *Response 1* for the pseudo-received pilot signal generation.

Fig.4 shows the impulse response selection algorithm to realize the beamforming criterion selection mentioned above. The receiver first determines the delay time *nmax* of the desired wave. Then, it calculates the normalized variation of the instantaneous amplitude of the estimated channel response *Pvari*, which is defined as

$$P_{\mathrm{vari}}(n) = \frac{1}{M}\sum_{m=1}^{M}\frac{\{|f_m(n)| - \overline{|f(n)|}\}^2}{\overline{|f(n)|}^2},$$

$$\overline{|f(n)|} = \frac{1}{M}\sum_{m=1}^{M}|f_m(n)|,$$

where n*(k)* denotes the estimated channel impulse response at the *n* th antenna sensor, and the receiver judges the angular spread of the incoming wave is large if *Pvari(k)* exceeds a threshold *Thvari*. If the angular spread of the desired wave is large, or else if the angular spreads of all the undesired waves are large, the equalizer selects *Response 1*, since the adaptive array can capture only the desired wave regardless of DoA patterns of the undesired waves. Otherwise, the equalizer calculates the DoA of each incoming wave from the phase differences of the estimated channel impulse responses. If there exists at lease one undesired wave whose DoA is within *ThDoA* from the DoA of the desired wave, the equalizer selects *Response 2*, otherwise, *Response 1*.

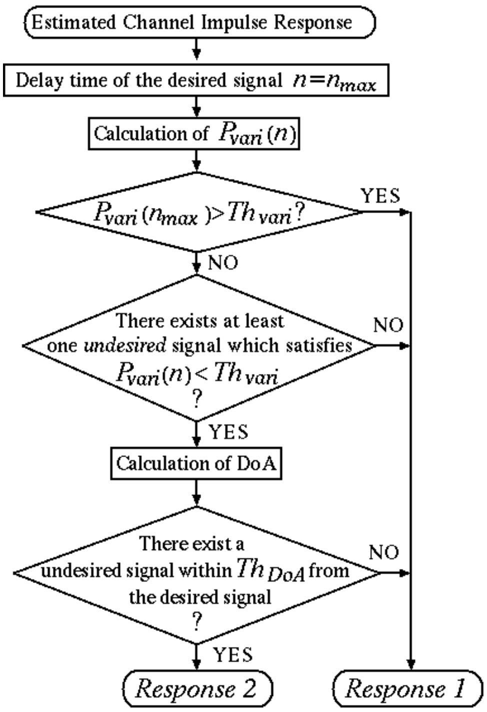

Figure 4- Beamforming Criterion Selection Algorithm

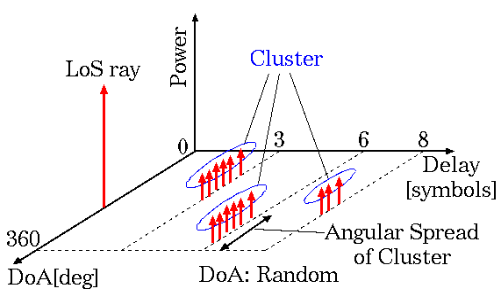

Figure 5- Space-Time Channel Model

Table I – System Parameter

	Proposed	ATDLA
Filter Length	Feedforward: 9 Feedback: 8	9 (or 3)
Total # of Weights	25	72 (or 24)
RLS Repetitions	Spatial: 50 Temporal: 50	50
Antenna Array	Circular Array (8 Sensors)	
Mod./Demod. Scheme	QPSK/Coherent	
Symbol Rate	100 [Msymbols/sec]	
Carrier Frequency	60 [GHz]	
Roll-off Factor	0.5	
Oversampling Factor	4	

4. Computer Simulation

A. Space-Time Channel Model

In agreement with measurements reported in [8] and [9], we use a line-of-sight (LoS) space-time channel model (Model A) defined in Fig.5, where delayed incoming rays form clusters. In the case of no LoS channel (Model B), the LoS ray in Fig.5 will be omitted. DoAs of the LoS ray and the clusters follow a uniform distribution of [0,360][deg], whereas distribution of the individual clusters is assumed to be a uniform distribution of [-45,45][deg]. Taking account of an indoor environment, we have chosen the Doppler spectrum of flat and the maximum Doppler shift of 150Hz.

B. System Parameters

System parameters used in all the computer simulations are summarized in Table I. Both the proposed system and the ATDLA have a circular array with 8 sensors, whose sensor spacing is half of the carrier wavelength. In the proposed system, *ThDoA* and *Thvari* were chosen to be 10.0[deg] and 0.07, respectively.

C. Numerical Results

Fig.6 shows the BER performance in channel model A. The BER performances of the proposed configuration with and without the beamforming criterion selection and the ATDLA with 72taps and 24taps are also plotted in the figure. The proposed system (cascade configuration with the selection algorithm) can achieve the lowest BER performance. Moreover, the comparison between the performance of the cascade configuration with and without the selection algorithm proves the validity of the selection algorithm. However, the BER performance of the ATDLA with 72taps has the largest inclination, and hence, diversity gain. This can be explained as follows. In channel model A, the adaptive array hardly can achieve diversity effect, since the path with the maximum power (LoS ray) has no angular spread. This means that the performance of the temporal processing determines the overall performance. The operation of the temporal processing in the proposed system, i.e. the DFE, is essentially the selection diversity, whereas the temporal processing in the ATDLA is capable of the combining diversity, therefore, the ATDLA can achieve larger diversity gain than the proposed system in this channel model.

Fig.7 shows the BER performance in channel model B. The proposed system can achieve the best performance among the four systems in this channel model, too. In channel model B, all the incoming rays have some angular spread, therefore, the spatial processing of the spatio-temporal equalizer dominantly determine the BER performance. This is the reason why the inclinations of the BER curves of all the systems are almost the same. Also, the slow rate of convergence in weight calculation due to the large number of weights could be the reason why the BER of the ATDLA with 72taps is higher than that of the ATDLA with 24taps.

5. Conclusion

In this paper, we have proposed a spatio-temporal equalization method, which employs a cascade configuration of an adaptive array without temporal filter and a DFE, and evaluated its performance comparing with the ATDLA. Owing to the beamforming criterion selectability, **the proposed equalizer can manage low computational complexity and good performance at the same time**.

We have shown the BER performance in the space-time channel models, which are based on measurement reports. From all the results, we have confirmed that the proposed system can achieve good performance with small number of weights, and hence, low computational cost.

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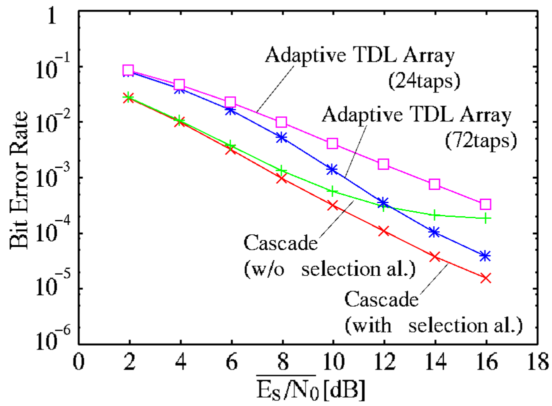

Figure 6- BER Performance (Model A)

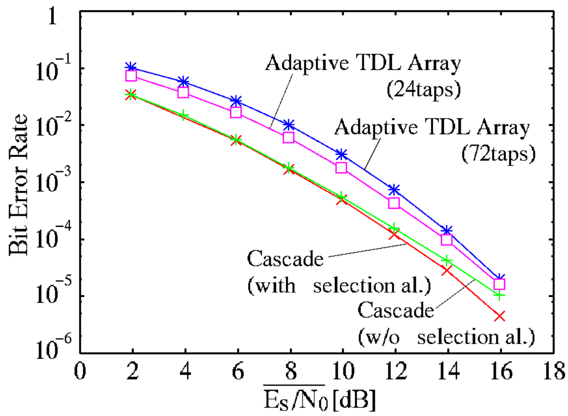

Figure 7- BER Performance (Model B)