A SPACE/TIME PRE-EQUALIZATION TECHNIQUE FOR DOWN-LINK SIGNAL TRANSMISSION IN TIME-DIVISION-DUPLEX (TDD) MOBILE MULTIMEDIA COMMUNICATIONS

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ABSTRACT

This paper proposes a new spatial and temporal (S/T) pre-equalization technique for time-division-duplex (TDD) mobile multimedia communication systems. Base station (BS) employs an adaptive array antenna (AAA) and an adaptive decision feedback equalizer (DFE) for up-link signal reception. The weight vectors for the up-link AAA and DFE are also used for pre-equalization of signal to be transmitted. With the S/T pre-equalization at the transmitter, the needs for equalizers at mobile station (MS) can be eliminated. In order to evaluate performances of the proposed S/T pre-equalization scheme, this paper uses a detailed propagation model which looks into the mobile propagation mechanism more in detail than conventional multipath models. Performances of the proposed S/T pre-equalizer are then demonstrated through computer simulations. The results show that the proposed scheme is effective in reducing effects of both inter-symbol and co-channel interferences.

1. INTRODUCTION

In mobile multimedia communications, an essential requirement is reliable and very high speed, say, more than 10 Mbit/s, signal transmission even though the received signal is, in most situations, distorted by frequency selectivity fading which causes inter-symbol interference (ISI). Co-channel interference (CCI) also distorts the desired received signal if the same frequency is reused in spatially separated but relatively close cells. Spatial and Temporal (S/T) equalization techniques have recently been considered as a solution to this problem, and several algorithms have been proposed for signal reception under such hostile environments [1][2]. With the proper use of S/T equalization techniques, ISI and CCI components, both appearing in the received desired up-link signal, can be effectively eliminated.

In frequency-division-duplex (FDD) systems, up- and down-links use different frequency bands. Hence, the down-link channel variables cannot exactly be estimated from the up-link channel parameters. This is not the case of time-division-duplex (TDD) systems, where both links use the same frequency bands. The down link channel parameters can easily be estimated through up-link signal reception, if the TDD switching period is short enough compared with the channel variation speed. Therefore, S/T pre-equalization techniques can also be used for the TDD down-link signal transmission to reduce ISI and CCI effects on the down-link signals received by MSs. By using S/T pre-equalizer at BSs, MSs need no equalizer, and hence it is effective in reducing the MS hardware scale.

This paper proposes a new S/T pre-equalization technique for down-link signal transmission in TDD multimedia mobile communication systems. Tomlinson-Harashima's pre-equalizer is used as a temporal pre-equalizer to eliminate the problem of the pre-equalizer itself becoming unstable [3][4]. Since the purpose of S/T pre-equalization is to reduce the MS receiver complexity, this paper focuses on down-link performances achieved by the proposed scheme, which is represented by down-link signal to interference power ratio (SIR) and bit error rate (BER).

A factor considered most important when evaluating performances of S/T signal processing under mobile communication environments is the spatial structure of the composite signal received by BS antenna. In fact, the direction-of-arrivals (DOAs) of the incident path components, representing the spatial structure of the received composite signal, depend on propagation mechanism. Therefore, instead of conventional multipath propagation models [5], more detailed propagation model which takes into account the spatial signal structure has to be used when simulations are conducted for performance evaluations of the S/T pre-equalization.

For the down-link SIR and BER evaluations, this paper uses a new propagation model which details the multipath propagation mechanism between transmitter and receiver: DOA of each path component and its average strength are simulated based on a ray tracing-like method. Rayleigh-distributed complex envelopes are then superimposed upon the path components.

This paper is organized as follows. The proposed S/T pre-equalization scheme is summarized in section 2. Results of computer simulations conducted to evaluate the SIR and BER performances of the proposed scheme are then presented in section 3.

2. SPACE/TIME PRE-EQUALIZER

2.1 Receiver

Figure 1 shows a block diagram of the system considered in this paper. The receiver consists of an AAA and a DFE, both having weighting taps which are adaptively updated for spatial and temporal equalization purposes, respectively. The extended weight vector $\boldsymbol{W}(i)$ is defined as

$$\boldsymbol{W}(i) = [\boldsymbol{W}_a(i), \boldsymbol{W}_e(i)]\,, \tag{1}$$

where sub-vector $\boldsymbol{W}_a(i) = [w_{a1}(i)\; w_{a2}(i) \cdots w_{aL}(i)]^{\mathrm{t}}$ is the weight vector for the L-element AAA and $\boldsymbol{W}_e(i) = [w_{e1}(i)\; w_{e2}(i) \cdots w_{eNt}(i)]^{\mathrm{t}}$ is the weight vector for the adaptive DFE having N_t feedback taps. Values of $\boldsymbol{W}$'s elements are determined so that the mean squared error given by

$$\left\langle |e(i)|^2 \right\rangle = \left\langle \left| d(i) - \boldsymbol{W}^{\mathrm{H}}(i)\, \boldsymbol{S}(i) \right|^2 \right\rangle \tag{2}$$

is minimized, where

$$\boldsymbol{S}(i) = [\boldsymbol{S}_r(i), -\boldsymbol{X}(i)]^t \tag{3}$$

with i being the symbol timing index, and $d(i)$ is the desired response of the overall S/T equalizer. $\boldsymbol{S}(i) = [r_1(i)\; r_2(i) \cdots r_L(i)]^{\mathrm{t}}$ is the snapshot vector of the AAA, and $\boldsymbol{X}(i) = [d(i-1)\; d(i-2) \cdots d(i-N_t)]^{\mathrm{t}}$ is the feedback signal vector of the adaptive DFE. An adaptive algorithm may be used to recursively update the extended weight vector $\boldsymbol{W}(i)$ symbol-by-symbol.

2.2 Transmitter

The transmitter transmits forward link signals by using the proposed S/T pre-equalization scheme. The weight vector $\boldsymbol{W}_{ta}$ for the AAA, used for the spatial pre-equalization, is the same as the up-link adaptive array weight vector $\boldsymbol{W}_a(i)$ obtained at the latest signal reception timing. This is because, in essence, the commonality in the spatial structure with the up- and down-links holds if the alternation between the signal transmission and reception periods is fast enough: the nulls in antenna's beam pattern should be directed towards the incident angles of the interference's path components to minimize the leakage of the desired MS's down-link signal.

A feedback loop is used in the down-link temporal pre-equalizer to form the reciprocal characteristics of the channel transfer function. The weight vector $\boldsymbol{W}_{te}$ used in the feedback loop for the temporal pre-equalization is the same as vector $\boldsymbol{W}_e(i)$ of the up-link adaptive DFE obtained at the latest signal reception timing.

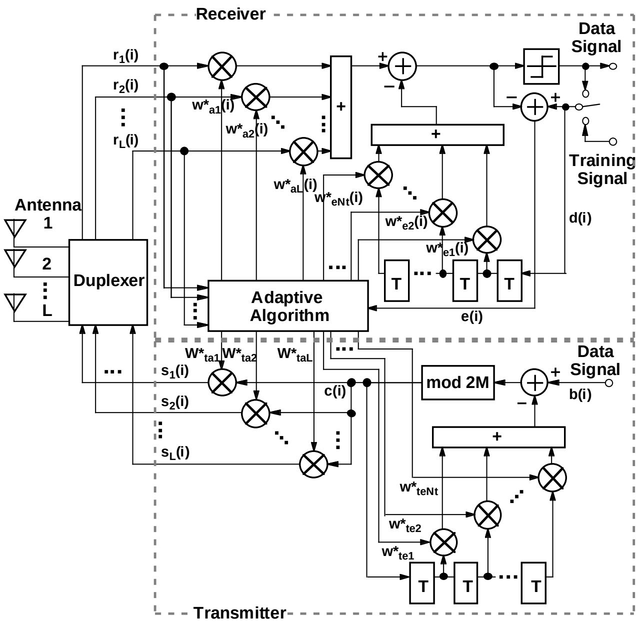


Fig. 1 Transmitter and Receiver

A problem in using a feedback loop to form the reciprocal channel characteristics is that the overall transfer function of the formed loop becomes unstable. This situation is typically encountered when the channel is in non-minimum phase mode. In this situation, the amplitude of the temporal pre-equalizer output signal increases as the timing index i increases, and finally diverges.

To avoid this problem, Tomlinson-Harashima's pre-equalizer is used in the feedback loop. The pre-equalizer output sequence $c(i)$ can be expressed as

$$c(i) = [b(i) - \boldsymbol{W}_t^{\mathrm{H}} \boldsymbol{X}_t(i)] \textit{ modulo } 2M \;\; \textit{in complex domain}\,, \tag{4}$$

where $b(i)$ is the down-link symbol sequence to be transmitted,

$$\boldsymbol{X}_t(i) = [c(i-1), c(i-2), \cdots c(i-N_t)]\,, \tag{5}$$

and M is the multiplicity of the in-phase and quadrature signal components with the modulation format used (M = 2 for QPSK). The purpose of the modulo $2M$ operation is to reduce $c(i)$ to the half-open interval ($-M$, M], thereby making the formed loop stable.

3. SIMULATIONS

3.1 Simulation Conditions

To verify the effectiveness of the proposed space/time equalization scheme, a series of computer simulations was conducted. Performance of the proposed scheme was evaluated under delay- and interference-rich multipath fading environments.

Table 1 summarizes the parameter values used in the simulations. The recursive least-squares (RLS) algorithm was used to update the weight vector $\boldsymbol{W}(i)$ for the proposed S/T per-equalizer. Each transmission burst consists of 32 training symbols and 128 data symbols. Signal reception and transmission were assumed to take place alternatively without a break. A hexagonal cell layout shown in Table 1 was considered. The numbers of cells are 57 and 133 for the reuse factor of 3 and 7, respectively. Hence, there are 19 BSs and 19 MSs in this configuration. Multiple propagation paths between each BS and each MS were simulated based on the model described in the next section.

3.2 Propagation Model

Table 2 summarizes the propagation model used in the simulations. The propagation loss according to Okumura formula with a distance attenuation factor of $\alpha = 3.5$ is first calculated for the distance between each MS and each of the 19 BSs. The attenuation due to log-normal shadowing with a standard deviation of 6.5 dB is superimposed over the distance loss, and then the received average signal strength P_r is obtained. The number L_p of propagation paths takes an integer value uniformly distributed over $1 \leq L_p \leq 5$. Each propagation path is assumed to experience reflections, times N_{ref} of which is uniformly distributed over $0 \leq N_{ref} \leq 2$. The attenuation due to a reflection is assumed to be 10 dB.

Because of the reflections, the overall propagation scenario is segmented into several sections. BS-to-reflection point section as well as reflection point-to-reflection point section is subjected to the free-space propagation loss, and reflection point-to-MS section as well as BS-to-MS section, if $N_{ref} = 0$, is subjected to the non line-of-sight propagation loss with $\alpha = 3.5$. As a result of this scenario, the total loss associated with each of the L_p propagation paths can be calculated. The received average signal strength P_r is then divided into L_p components corresponding to the L_p paths: each path's average strength is, therefore, in proportion to its total loss.

Fading complex envelope variations, which are complex Gaussian random variables, and statistically independent among the paths, are further superimposed upon the L_p paths. The fading variation on each path is frequency-flat, but because of delays imposed on the paths, received composite signal suffers from frequency-selective fading.

DOA of each propagation path is set according to a normal distribution whose average is the look-angle from the considered BS to each MS. The standard deviations of the DOA distribution are, in general, parameters to be set so that the propagation reality can be well modelled. In this paper, those with the desired and interference paths assumed to be 60 and 30 degrees, respectively.

Table 1 Simulation Conditions

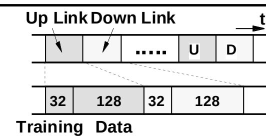
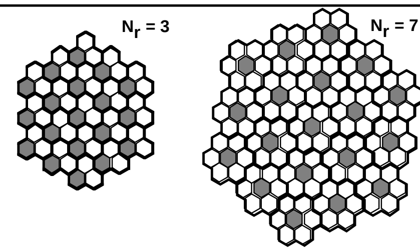
Modulation	QPSK
Spatial Equalizer	Circular Array, 8 elements
Temporal Equalizer	DFE
Adaptive Algorithm	RLS
Frame Format	
Cell Configuration	

Table 2 Propagation Conditions

Fading Model	Rayleigh
SD of Shadowing	6.5 dB
Propagation Paths	5 (Max)
SD of DOA	60 deg for desired signal 30 deg for interference
Path Reflection Number	2 (Max)
BS Antenna Height	40 m
MS Antenna Height	1.5 m

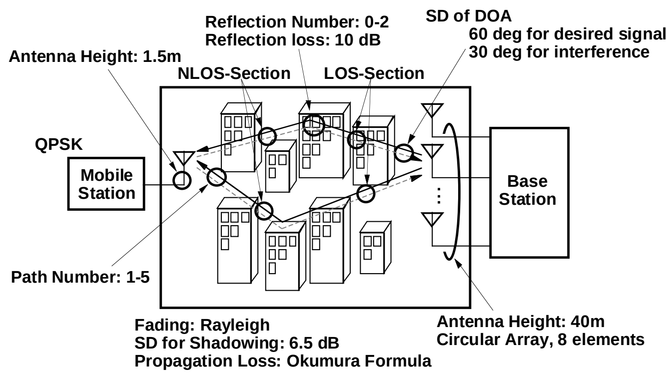


Fig. 2 Propagation Conditions

In the simulations, up-link signal transmission first took place, and the extended weight vector $\boldsymbol{W}(i)$ for the up-link AAA and DFE was generated. By using $\boldsymbol{W}(i)$, the weight vectors $\boldsymbol{W}_{ta}$ and $\boldsymbol{W}_{te}$ for the S/T pre-equalizer were determined. The proposed S/T pre-equalization process took place independently at each of the 19 BSs, and the reference MS's down-link SIR and BER were then evaluated.

3.3 SIR Performance

For the hexagonal cell layout described in Section 3.1, SIR distribution in a reference (central) cell was first evaluated. One MS was located in each of the reference and co-channel cells. The MS's geographical location was uniformly distributed within each cell.

Figure 2 shows the calculated cumulative distribution function (cdf) of the down-link SIR. The normalized Doppler frequency $f_D T_b$ is set to be 0, where T_b is a burst length of up- and down-links. The cdf curve with the omni-directional antenna is also plotted. It is found that with N_r = 7, the proposed S/T pre-equalization scheme can improve the down-link SIR by about 7 dB at 5 % cumulative probability. The SIR performance of the proposed scheme with N_r = 3 is almost equivalent to the omni-antenna case with N_r = 7.

3.4 BER Performance

The average down-link BER performance with the proposed S/T pre-equalization scheme was then evaluated with the number N_i of interference MSs as a parameter. The number of propagation paths L_p between each MS and each BS was fixed to 5 in this case, but the 5 paths were assumed to have different delays, resulting in fading frequency selectivity. The parameter values related to the path loss and shadowing were the same as those used in the simulation for the cdf evaluation.

Results are shown in Fig. 3. The normalized maximum Doppler frequency $f_D T_b$ was set to 0. The theoretical QPSK BER curve is also plotted under the (*static*) non-fading condition. It is found that in the absence of co-channel interference, the BER performance achieved by the proposed S/T pre-equalization scheme degrades from the *static* BER by about 0.5 dB at 10^{-4} because of the modulo operation. With the presence of the co-channel interference, the curve plateaus at the BER range of 10^{-5}. This is because even with the proposed S/T pre-equalization, the interference components received by the desired MS cannot completely be eliminated. The BER floor corresponds to the desired signal-to-*residual* interference power ratio.

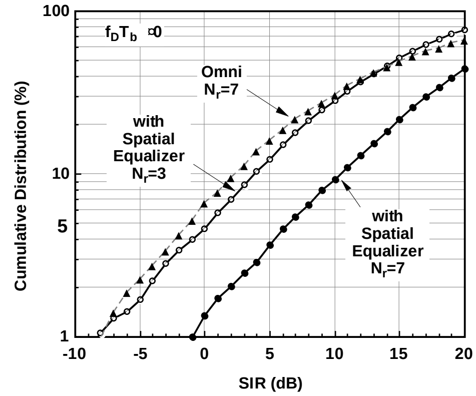


Fig. 3 SIR Performance

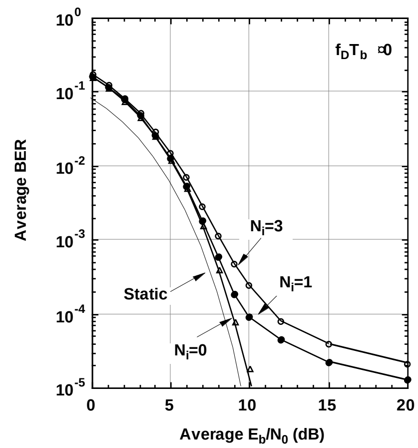


Fig. 4 BER Performance

4. CONCLUSION

This paper has proposed a new spatial and temporal pre-equalization technique for mobile multimedia communications. SIR and BER performances in multipath fading environments were demonstrated through computer simulations using a ray tracing-like propagation model. It has been shown that the proposed scheme is effective in reducing ISI and CCI under delay- and interference-rich multipath fading environments.

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