Blind Adaptive Spatial Equalisation in S-UMTS Systems

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Abstract

Today there is an increasing demand for a higher signal rate in both the existing and future mobile communication system. With higher signal rate, the intersymbol interference (ISI) problem will also increase. In this paper, a Spatial Adaptive Constant Modulus Algorithm (SA-CMA) Equaliser will be presented that will compensate for the ISI problem. A Least-Mean-Squared (LMS) solution will be also presented for comparison purpose.

1. Introduction

Terrestrial cellular networks and mobile satellite system are expected to converge towards a future integrated satellite/terrestrial mobile communication network, in order to increase capacity and improve performance of existing systems. This integrated system is called Satellite-Universal Mobile Telecommunication System or S-UMTS for short. The S-UMTS systems are expected to handle various forms of information such as speech, image and data and consequently there is a need for a much higher signalling rate then what are available today. When the signalling rate is increased, the delay spread (due to multipath propagation) of the channel will introduce significant levels of intersymbol interference (ISI). For TDMA and FDMA systems, the ISI can be reduced by using an equalisation scheme that has the ability to self-adapt to the time varying channel characteristics. Therefore, for S-UMTS there is a great demand for high performance and computationally efficient equalisers. Further performance enhancement can be achieved by introducing several antenna elements at the receiver side (i.e., adding spatial diversity feature) [1]. One advantage with an array antenna is the ability to avoid local fading minima; that is when one of the antenna elements can not detect the desired signal, the other elements still have this capability (by appropriate spatial separation between the elements).

2. Spatial Adaptive Equalisation

In conventional (non-blind) equalisers, the optimal weights of the equaliser are estimated by transmitting a predetermined data (training) sequence. One of the most well known non-blind adaptive algorithms is the LMS algorithm. The performance of the equaliser is heavily dependent on the quality of the desired signal. The usual way to obtain a desired signal is to use a training sequence which is known to the receiver. This types of training techniques reduces the system capacity (number of users) in mobile communications. For such applications, a blind equaliser which can adapt its tap weights without the aid of a training sequence seems more appropriate. Blind equalisers rely on some other kind of a*priori* information about the transmitted signal, such as spatial knowledge or signal characteristics. The CMA algorithm is one of the most used and tested blind algorithms. The algorithm is suited for signals that have a constant amplitude; which is the case in our S-UMTS model where a QPSK modulated signal is transmitted over the channel. Our spatial adaptive equaliser, with two antenna elements, is shown in Fig. (1) where the *adaptive algorithm* can be either LMS or CMA algorithm. The distance between the antenna elements is chosen to a half of the wavelength of the transmitted signal; in this setting the receiver has the ability to avoid local fading minima.

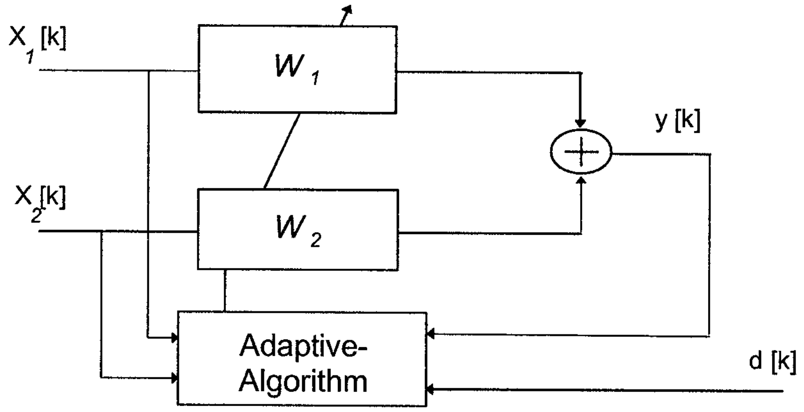

Figure (1): A Spatial Adaptive Equaliser

2.1 The LMS and the CMA algorithm

The LMS and the Godard (CMA) [2] adaptive equalisers have some similarities and basic differences. For both algorithms, the adaptive filter output $y[k]$ and the weight update equation is given by :

$$y[k] = \mathbf{w}^{\mathrm{H}}[\mathrm{k}]\,\mathbf{x}[\mathrm{k}]$$

$$\mathbf{w}[\mathrm{k}+1] = \mathbf{w}[\mathrm{k}] + \frac{\mu\,\mathbf{x}[\mathrm{k}]\varepsilon^{*}[k]}{\eta_k}$$

where ^{H} denotes the complex conjugate and transpose operation, the * operator denotes complex conjugate and $\mathbf{x}[\mathrm{k}]$ and $\mathbf{w}[\mathrm{k}]$ are the input and weight vectors that are defined by:

$$\mathbf{x}[k] = [x_1[k]\ x_1[k-1]\ \cdots\ x_1[k-L+1]\ x_2[k]\ x_2[k-1]\ \cdots\ x_2[k-L+1]\ ]^T$$

$$\mathbf{w}[k] = [\ w_{11}[k]\ w_{12}[k]\ \cdots\ w_{1L}[k]\ w_{21}[k]\ w_{22}[k] \cdots w_{2L}[k]\ ]^T$$

where L is the filter length and T denotes transpose operation.

However, the cost function J (also known as the performance or dispersion function), the error function $\varepsilon[k]$ and the normalisation factor η_k are quite different. In data aided equalisers, the adaptation of the equaliser taps is carried out by minimising the *mean square error (MSE)* between the equaliser output and the desired data symbol which is made available from a training sequence. That is, the LMS algorithm minimises a convex cost function J, which is given by $J = E[\varepsilon^{2}[k]]$ where E denotes an ensemble average operation and $\varepsilon[k] = d[k] - y[k]$ is the error function and $\eta_k = \mathbf{x}^{\mathrm{H}}[\mathrm{k}]\mathbf{x}[\mathrm{k}]$,

However, in the case of blind equalisation the desired data symbols is not available. In this case the equaliser taps are updated using an algorithm that minimises a certain error function, which is formed by observing the equaliser output and employing some *a priori* information about the transmitted data constellation statistics. TheGodard algorithm minimises a non-convex (non-linear) cost function J [2], which provides a measure of the amplitude fluctuation. TheGodard cost function J_{pq} is defined as $J_{pq} = E[(|y[k]|^{p} - 1)^{q}]$ and for $(p = 1,\ q = 2)$ the error-correction term $\varepsilon[k]$ is given by $\varepsilon[k] = y[k] - \frac{y[k]}{|y[k]|}$ and replaces the usual error signal in the LMS algorithm [2].

The normalisation factor is defined by ,$\eta_k = \frac{1}{L}\sum |\mathbf{x}[k]|$ where $|\cdot|$ denotes the absolute value. The normalisation factor will improve the convergence of the algorithm and is not included in the original paper byGodard [2]. Due to the phase insensitivity of the CMA algorithm the carrier phase must be recovered after the adaptive processing. This problem can be solved, for example, with a phase lock loop circuit.

3 Channel Model

The equalisers were tested on the following simplified version of the ACTS project NEWTEST channel model [3].

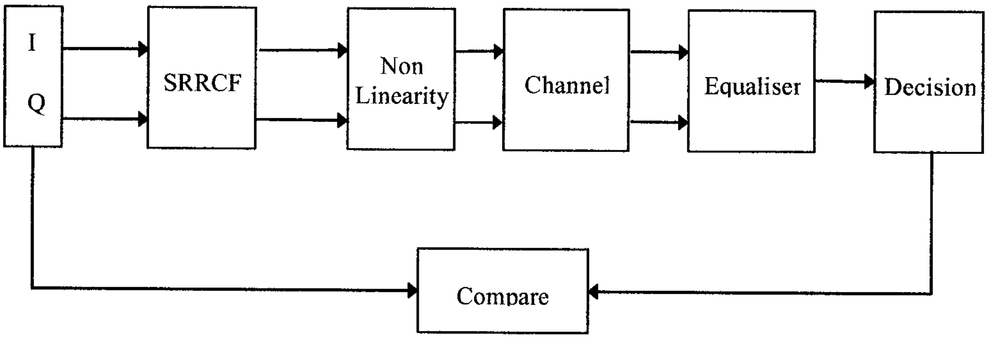

Figure (2); Simplified Channel Model

The different functional blocks in Fig. (2) are explained below :

- I-Q function which creates the in-phase andquadrature components of signal that will be transmitted through the channel.
- The SRRCF block, band-limit the signal with the help of a Square Root Raised Cosine Filter and over-sample the signal.
- The non-linearity block simulate the effects of the non-linear travelling wave tube (TWT) amplifiers.
- The channel block simulates thedoppler, noise, multipath and attenuation effects on the transmitted signal.
- A symbol decision is made at each symbol time point and then compared to the original transmitted signal and the Symbol Error Rate (SER) is calculated

4 Simulation Results

In this section, we present simulation results to show the performance of the CMA and LMS equalisers in a multipath, noisy S-UMTS channel. Two versions of the equaliser will be simulated: the symbol rate sampling and the fractionally (over-sampling) spaced sampling equaliser [3]. Results will be provided for single channel as well as dual channel equalisers. In all simulations the up-link SNR has been fixed to 15 dB and the TWT amplifiers are assumed operating at their saturation point thus worst case for the non linearity effects meanwhile the speed of the vehicle and the down-link SNR was varied in the different simulations. In all the fractionally spaced equaliser simulation an over-sampling with a factor 8 has been used. The SER value is calculated after the different algorithms has converged and 200 erroneous decisions have occurred. Fig. (3) shows that the fractionally spaced CMA equaliser is robust to the speed of the vehicle and the difference becomes more notable for SNR higher than 15 dB's. The benefit of using fractionally spaced CMA equaliser instead of symbol rate equaliser is shown in Fig. (4). The improvement in SER-value is at the cost of higher computational load. The gain when using two antennas instead of a single antenna is shown in Fig. (5) and the gain is achieved by the fact that a fading dip is less probable to occur at two elements at the same time. Finally in result plot Fig. (6), CMA and LMS equalisers (fractionally spaced) are compared. It is clear from this figure that the LMS algorithm out perform the CMA algorithm; this result is expected since the CMA is a blind algorithm while the LMS requires a predetermined training signal. An other difference between the algorithms is that the CMA algorithm needs 5 times more training data to converge than the LMS algorithm.

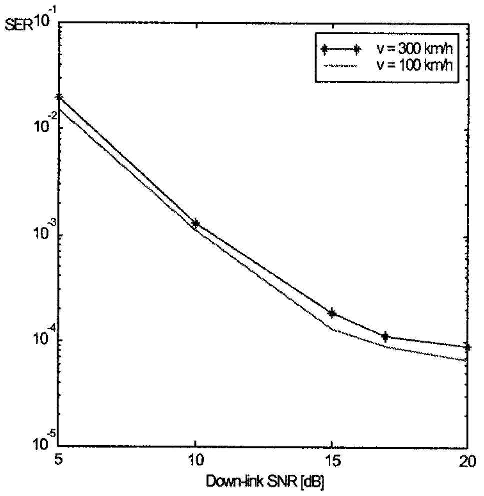

Figure (3); Fractionally spaced CMA simulations when the speed of the mobile is altered.

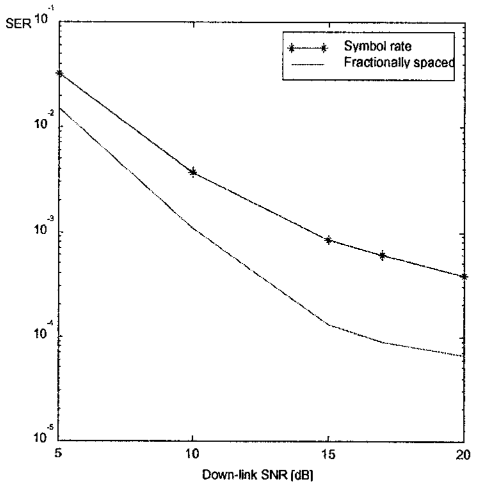

Figure (4); Fractionally spaced CMA vs. symbol rate CMA equaliser (v = 100 km/h) .

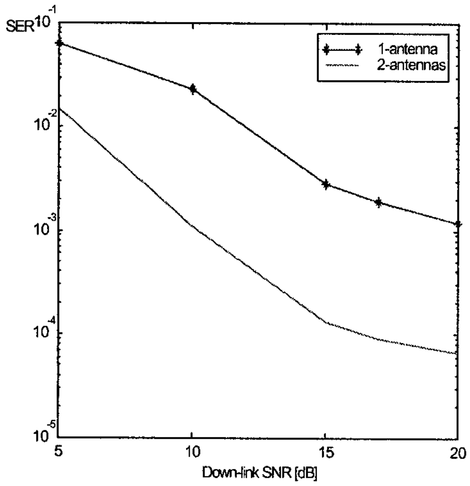

Figure (5); Fractionally spaced CMA equaliser using two antennas compared to the one antenna solution (v = 100 km/h).

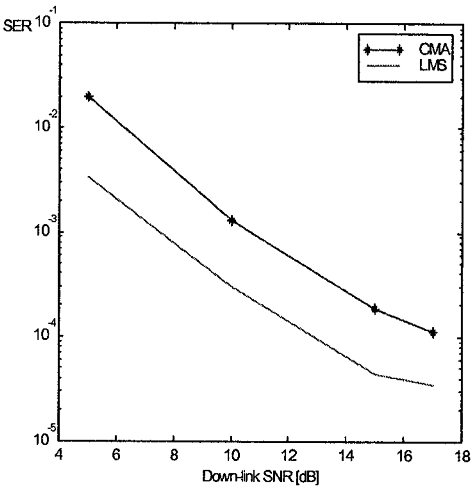

Figure (6); Fractionally spaced CMA equaliser compared with a fractionally spaced LMS equaliser (v = 300 km/h) .

5 Conclusions

In this paper, a blind fractionally spaced equaliser has been presented that is controlled by a normalised CMA algorithm. The results has shown that the equaliser is robust to non-linearity in amplifiers and Doppler-shift and has a SER value in the range of 10^{-4} - 10^{-5} for down-link SNR above 15 dB's. These facts makes the equaliser well suited to be an initial equaliser that opens up the decision eye. When the decision eye is open other standard equalisation schemes, following the CMA equaliser, can suppress the SER value even further.

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