Phase Tracking and CCI Cancellation in Severely Faded Rayleigh MIMO Channel

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ABSTRACT

Multi input multi output system (MIMO) has become a viable option to meet the demand of high data rate wireless communication. But MIMO system performance is severely affected by the presence of co-channel interference (CCI). CCI cancellation in MIMO channel therefore is a challenging area of research. This paper provides a Kalman Filter based CCI cancellation approach which is connected to phase tracking performance of the system. Experimental result in the severely faded Rayleigh channel show that Kalman filter based approach for CCI cancellation in the considered MIMO channel provides reliable results and can thus prove to be a satisfactory CCI cancellation technique in future.

General Terms

MIMO,RayleighChannel,Co-channelInterference(CCI),NLOS BPSK modulation.

Keywords STBC, CCI,KF

1.INTRODUCTION

In recent years, researchers have found that substantial amount of performance gain of transmitted and receive diversity can be achieved by using multiple antennas. Multiple- Input Multiple-Output (MIMO) technology seems to be a cornerstone of many wireless communication systems due to the potential increase in data rate and performance of wireless links offered by transmit diversity and MIMO technology. Space-time Block code (STBC) is a method usually employed into MIMO wireless communication systems to improve the reliability of data transmission using multiple antennas. The use of STBC with diversity gains derived from MIMO set-up provide improved performance in faded wireless channels.

Co-channel interference (CCI) in wireless channel is a degrading phenomenon. It is more so with MIMO systems and the capacity of such systems are limited considerably by the presence of CCI. Therefore, CCI cancellation is challenging area and continues to attract research.

The combination of coding with spatial diversity opens up new dimensions in wireless communications, and can offer effective solutions to the challenges faced in realizing reliable.

high-speed wireless communication links [1] [2].The overall performance can be further enhanced if the CCI in the channel could be cancelled. In the present paper, we describe a Kalman filter based CCI cancellation approach which is connected to phase tracking performance of the STBC coded MIMO system.

This paper is organised as follows. Section II describes the basic theoretical notions of the system. Section III describes the channel estimation technique using Kalman. Section IV describes the system model for co-channel interference setup. Experimental details and related results are included in Section V. Finally Section VI concludes the paper.

2. BASIC THEORTICAL NOTIONS

Wireless designers constantly seek to improve the spectrum efficiency, capacity, coverage of wireless networks link reliability and cancellation of interferences creeping out of different reasons. Space-time wireless technology that uses multiple antennas along with appropriate signalling and receiver techniques offers a powerful tool for improving wireless performance. Space-time block codes have a most attractive feature of the linear decoding/detection algorithms and thus become the most popular among different STC techniques. The use of STBC and MIMO has proven to be an effective combination. This section provides a brief description of STBC, CCI, Rayleigh fading and related channel aspects considered for the work.

1.1 Rayleigh Multipath Fading Channel

The propagation environment for any wireless channel is either indoor or outdoor may be subject to LOS (Line-of-Sight) or NLOS (Non Line-of-Sight). A probability density function of the signal received in the LOS environment follows the Rician distribution, while that in the NLOS environment follows the Rayleigh distribution. In mobile radio channels, Rayleigh distribution is commonly used to describe the statistical time varying nature of the received envelope of a flat fading signal or the envelope of an individual multipath component [1]. The received signal is modelled as bandwidth at which frequency selectivity becomes relevant.

$$r(t) = \alpha(t)s(t) + \eta(t) \qquad (1)$$

where s(t) is the signal,

$$\alpha(t) = x(t) + jy(t) = a(t)ej\phi(t) \qquad (2)$$

is a zero-mean complex Gaussian. Denoting x and y as samples taken from x(t) and y(t) where $x \sim \aleph(o, \sigma 2)$ and $y \sim \aleph(o, \sigma 2)$.

Then α is described by a zero mean complex Gaussian random variable

$$f_{x,y}(x,y)=(1/2\pi\sigma^2)\exp(-(x^2+y^2)/2\sigma^2); \qquad (3)$$

Fading envelop (amplitude), $a = \sqrt{x2 + y2}$

Fading phase, $\phi = \arctan(y, x)$.

1.2 Space Time Block Codes (STBC)

In general multiple antennas are used to achieve spatial diversity and to achieve time diversity the transmission is repeated n times. Scope of diversity is expanded by using multiple antennas at both the receiver and transmitter. The capacity of multi-antenna systems far exceeds that of a single antenna system and capacity grows at least linearly with the number of transmit antennas as long as number of received antenna is greater than or equal to number of transmit antennas. STC were first introduced by Vahid Tarokh, Nambi Seshadri and Robert Calderbank from AT&T research labs in 1998 as a novel means of providing transmit diversity for the multiple antennas fading channel. These STCs achieve significant error rate improvements over single-antenna systems. Their original scheme was based on trellis codes but the simpler block codes were utilised by Siavash Alamouti [14], and later Vahid Tarokh, Hamid Jafarkhani and Robert Calderbank [15] to develop STBCs. STC involves the transmission of multiple redundant copies of data to compensate for fading and thermal noise in the hope that some of them may arrive at the receiver in a better state than others

1.3 Co-channel interference (CCI)

MIMO architectures are useful for combined transmit receive diversity. For its parallel mode of transmission, MIMO system offer high data rate in narrow bandwidth .MIMO system is characterized by multiple antenna elements at the transmitter and receiver, have demonstrated the potential for increased capacity in rich multipath environments.

A MIMO system input-output relationship can be written as

$$x(k)=H(k)s(k)+v(k) \qquad (4)$$

where x(k) is M×1 vector with xi(k),i=1,…,M ,s(k) is N×1 vector of the input symbols v(k) is an additive noise vector, H(k) is M×N channel matrix with elements hij(k),1,…,M,j=1,2…..,N denoting the transfer function between the jth transmit and ith receive antenna respectively. Propagation related variations modeled by Rayleigh, ITU pedestrian and vehicular channels and Rician distribution can be included in matrix H.

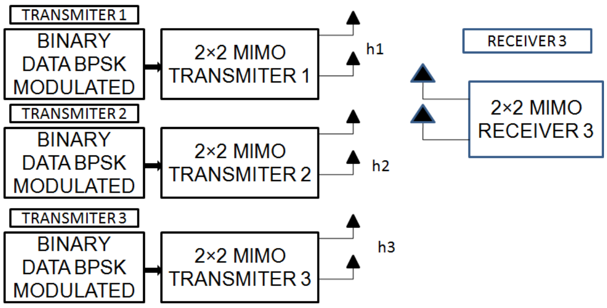

Fig1: A generic MIMO scheme with interferer

Considering the presence of CCI, the expression (4) can be modified as below:

$$\mathbf{x}(k)=\mathbf{H}(k)\mathbf{s}(k)+\sqrt{\frac{\mathbf{P}}{\mathbf{L}}}\sum_{i=1}^{L} hi(k)si(k)+\mathbf{v}(k) \qquad (5)$$

where P is constant interference power, L is the number of interferer, hi(k) is the channel vector of the ith interferer and rest of the terms as described with reference to equa (1).A generic set-up depicting a MIMO arrangement with certain no of interferer is shown in Figure1.

Here propagation taking place through channel H while interference signal si(k) reach the receiver end through another set of channel taps denoted by $\sum_{i=1}^{L} hi(k)$.Receiver receives the CCI affected signal.

1.4 Kalman Filter

In 1960, R.E. Kalman published his famous paper describing a recursive solution to the discrete data linear filtering problem. The Kalman filter is a set of mathematical equations that provides an efficient computational (recursive) means to estimate the state of a process, in a way that minimizes the mean of the squared error. The filter is very powerful in several aspects: it supports estimations of past, present, and even future states, and it can do so even when the precise nature of the modelled system is unknown [8]. Kalman Filter estimation is quite common in the literature at least for single user channel. In [9] and [10] the KF is used for tracking MIMO channels based on a low order autoregressive (AR) model. However, exact modelling of fast time varying channel with a low order model is impossible since the AR functions are irrational and higher order statistics are needed.

Process to be estimated: The Kalman filter estimates the state x€Rn of a discrete-time controlled process that is governed by the linear stochastic difference equation

$$x_k = Ax_{k-1} + Bu_{k-1} + w_{k-1} \qquad (6)$$

with a measurement $z \text{€} R^m$ that is

$$z_k = Hx_k + v_k \qquad (7)$$

The random variables wk and vk represent the process and measurement noise respectively. They are assumed to be independent of each other, white, and with normal probability distributions

$$p(w) = N(0, Q), \qquad (8)$$

$$p(v) = N(0, R).$$

The n × n matrix A in the difference equation 6 relates the state at the previous time step k - 1 to the state k at the current step. The n × l matrix B relates the optional control input u€Rl to the state x. The m × n matrix H in the measurement Equation 7 relates the state to the measurement zk [7] [8].

Table1: Discrete Kalman filter time update and measurement update

$$x_k = A\hat{x}_{k-1} + Bu_{k-1}$$

$$P_k = AP_{k-1}A^T + Q$$

$$K_k = P_kH^T / (HP_kH^T + R)$$

$$\hat{x}_k = \hat{x}_k^- + K(z_k - H\hat{x}_k^-)$$

$$P_k = (1 - K_kH)P_k$$

The a priori state estimate at step k is defined as $\hat{x}_k^- \in \Re^n$ given knowledge of the process prior to step k, and $\hat{x}_k \in \Re^n$ to be a posteriori state estimate at step k given measurement zk. a priori and a posteriori estimate errors are

$$\bar{e_k} = x_k - \hat{x}_k^-$$

$$e_k = x_k - \hat{x}_k.$$

The *a* priori estimate error covariance is then

$$\bar{P_k} = E[\bar{e_k}\bar{e_k^T}]$$

and the *a posteriori* estimate error covariance is

$$P_k = E[e_k e_k^T]$$

An a posteriori state estimate $\hat{x}_k$ can be computed as a linear combination of an a priori estimate $\hat{x}_k^-$ and a weighted difference between an actual measurement zk and a measurement prediction Hx_k.

$$x_k = \hat{x}_k^- K(z_k - H\hat{x}_k^-)$$

The difference $z_k - H\hat{x}^-_k$ is called the measurement innovation, or the residual. The n × m matrix K is chosen to be the gain or blending factor that minimizes the a posteriori error covariance.

$$K_k = \bar{P}_kH^T(H\bar{P}_kH^T + R)^{-1}$$

$$K_k = \bar{P}_kH^T / (H\bar{P}_kH^T + R)$$

The specific equations for the time and measurement updates are presented in Table 1. After each time and measurement update pair, the process is repeated with the previous a posteriori estimates used to project or predict the new a priori estimates [8].

3. SYSTEM MODEL

We have considered in our setup single-user link with two co-channel interferer. We assume the desired user has 2 transmit antennas, the two other interfering user has 2 transmit antennas each, and there are 2 receive antennas of the desired user. The desired and the interfering users transmit data at the same rate.Kalman Filter is an efficient recursive algorithm which estimates the state of a dynamic system from a series of noisy measurements. Kalman filter has been applied in communication systems since 1970s and it could also be applied to track the states of time varying channels, the state variable is defined as the channel states, which can be modelled as Auto regressive model, because it reflects the statistics of time varying channel. The system model for co-channel interference set up in wireless communication is depicted in Figure 2.The received signal at the Receiver 3 is a complex signal full of interfered signals. This signal is estimated with the Kalman filter and the original signal is recovered approximately in the receiver.

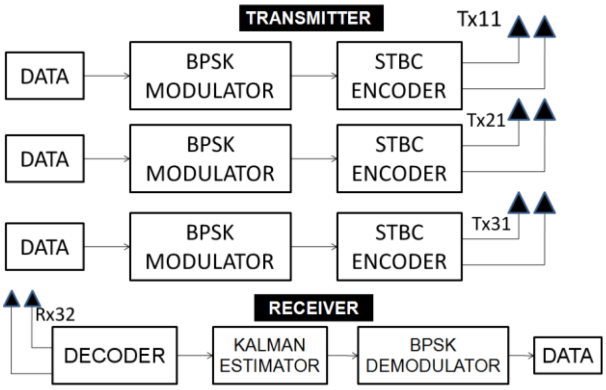

Fig.2. Transmitter and receiver structure of co-channel interference setup.

The state space equations for tracking the MIMO channel can be expressed as:

$$h(t+1) = A(t)h(t)$$

$$s(t) = C(t)h(t) + v(t)$$

where *h* is the channel tap, *A* is a time-varying transition matrix, *C* is the observation matrix and *v* is the measurement noise vector. On the receive antenna, the noise *n* has the Gaussian probability density function with

$$p(n) = 1/\sqrt{2\Pi\sigma^2}\exp(-(n-\mu^2))/2\sigma^2$$

with $\mu_{hi,j} = 0$ and $\sigma_{h\ i,j}^{2} = No/2$. A first-order Auto-Regressive (AR) model provides a sufficient model for time varying channels. Therefore, *A* can be a diagonal matrix of autoregressive model factor *α*, where

$$\alpha = E[h_{ij}(t+1) * h_{ij}^*(t)]$$

The Kalman filter equations for MIMO channel are divided into two parts. First part is the predictor:

$$\tilde{h}(t+1|t) = A(t)\tilde{h}(t|t)$$

$$P(t+1|t) = A(t)P(t|t)A^{*T}(t)$$

$$\varepsilon(t) = s(t) - C(t)\tilde{h}(t+1|t)$$

$$K(t) = P(t+1|t)C^{*T}(t)[C(t)P(t+1|t)C^{*T}(t) +$$

And the second part is the update:

$$\tilde{h}(t+1|t+1) = \tilde{h}(t+1|t) + K(t)\varepsilon(t)$$

where, $R_v = \beta I$ and β is a covariance of the noise vector v. The K matrix is called the Kalman gain and the P matrix is called the estimation error covariance.

4. EXPERIMENTAL RESULTS

In this section, simulation results and are presented. In this work, range of Signal to Noise ratio(SNR) considered is −10 to 10 dB. The channel experienced by each transmit antenna is independent from the channel experienced by other transmit antennas. For the transmit antenna, each transmitted symbol gets multiplied by a randomly varying complex number hi,j . As the channel under consideration is Rayleigh, the real and imaginary parts of hi,j are Gaussian distributed. having mean μh= 0 and variance σh2 = 1/2.

Table 2: Parameters adopted for the systems

PARAMETERS	ADOPTED VALUES
Multiple antenna system	MISO, MIMO
Transmitter antenna	TX= 2
Receiver antenna	RX=1, 2 respectively
Modulation schemes	BPSK and QPSK
Signal to Noise Ratio (SNR)	-10 to 10 dB
Frequency selective channel	Rayleigh fading

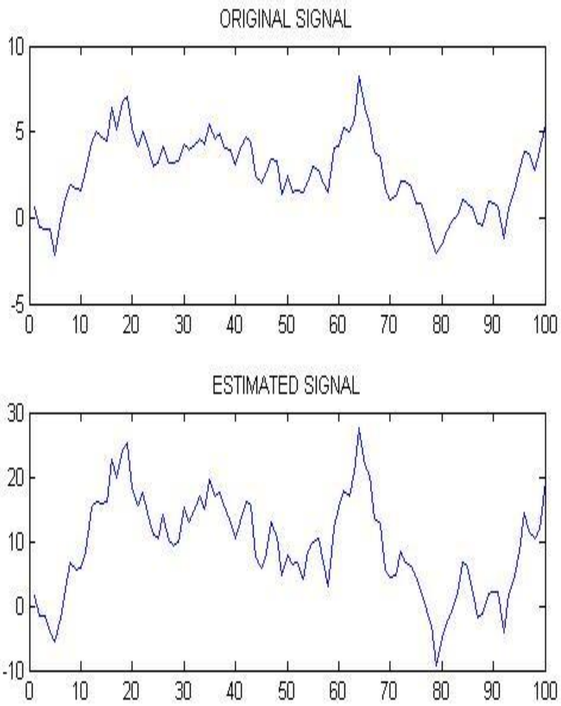

Fig 3. Kalman Filtering Results

The channel experienced between each transmit to the receive antenna is randomly varying in time. The performance of the Kalman estimator proposed here seems to have performed well to that of some similar works done in severely faded environments over the range of SNR −10 to 10 dB . The components of the system and channel parameters during the work are summarized in Table II.

The performance of the channel estimator based on Kalman filter is tested through simulations for CCI affected signal is performed and the recovered signal almost estimates the original signal.

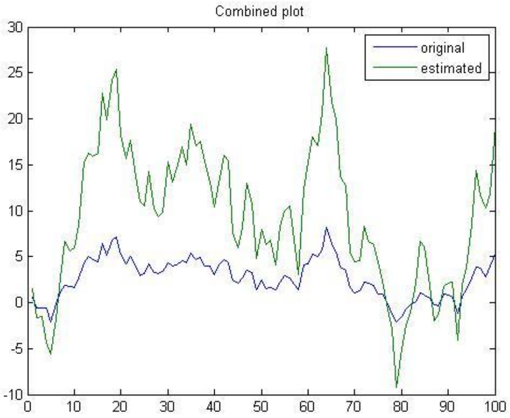

Fig 4:The composite plot showing estimated and original signal of co-channel interfered signal.

The tracking of the phase of the CCI affected signal is carried out and it was seen that Kalman filter is able to track the original signal successfully. The results are shown in Figure 5. Fading causes magnitude variation in the wireless channel.

The receiver must be able to successfully track the performance of the signal. Kalman Filter is approximately able to track the signal.

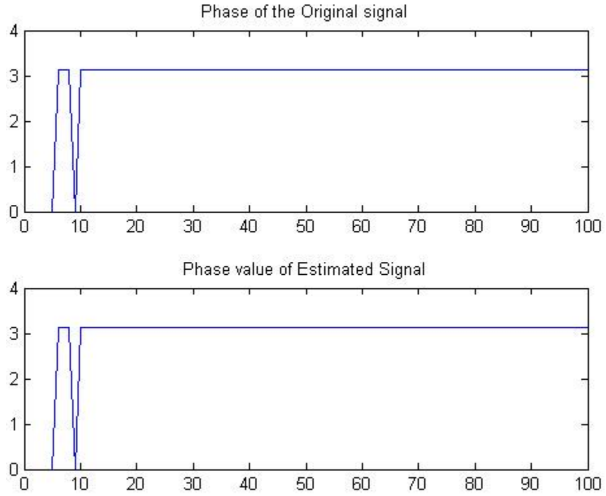

Fig5:Phase tracking by Kalman Filter

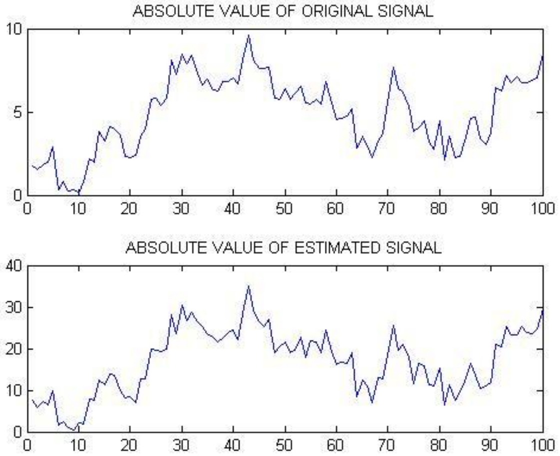

Fig 6 : Magnitute tracking by Kalman Filter

5. CONCLUSION

Co-channel interference is a vital problem in the MIMO channel. We have assumed two interference MIMO channel hampering the signal reception of the third MIMO channel. In this work Kalman Filter is used to estimate the signal and approximately identical signal is received at the receiver as was transmitted. Signal tracking was carried out to find the phase information of the original and estimated signal.

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