Selective interference cancellation using Kalman filtering

A. Pudeyev, A. Maltsev, A. Rubtsov , S. Tiraspolsky
Advanced Development
Intel Corporation, Mobility Group, SBG
Nizhny Novgorod, Russia

Abstract— **In present paper we have investigated a co-channel interference cancellation technique based on the tracking only a limited number of strongest interferers. With the assumption of synchronous interferers operation with overlapping but different training signals, Kalman filtering may be used for interfering users channel estimation and following calculation of interference correlation matrix. Such in-time correlation matrix estimate exploited in ZF or MMSE based interference cancellation. Developed algorithms may be used in next generation of the WiMax systems.**

***Keywords-** Mobile and wireless vehicular communication systems (Mobile WiMAX); OFDM(A), interference cancellationx, Kalman filtering*

I. Introduction

The IEEE 802.16 Working group developed a new standard, commonly known as WiMax, for broadband wireless access with high data rates [1]. The most suitable scenario for the urban environment (non-LOS operation, large number of users) is the WirelessMAN OFDMA specification. This air interface specifies up to 2048-carrier OFDM scheme. Multiple access is provided by assigning a subset of the carriers to an individual receiver. The most significant performance-limiting factor of such cellular networks is interference, and the ways to decrease its impact are the matter of many papers [2]. However, most of them are devoted to the problem of BS receivers that need to suppress interference from a large number of independent transmitters. In this paper, we address downlink (mobile) receiver design that should be able to suppress interference from just a few neighboring base stations. The first step of the proposed method of selective interference cancellation is estimating the dominant interference sources, then initialization of the Kalman filter and finally, using it for estimation of the main channel and channels of the several interfering BSs, obtained at the first step. Interfering BSs channels then used for interference correlation matrix calculation and ZF interference cancellation.

II. Problem Statement

Consider a typical urban scenario, when base stations (BSs) are closely located, thus creating the co-channel interference (CCI) which severely decreases system performance. In the downlink (DL) part of the frame, let us assume that all BSs operate synchronously. Assume that pilot subcarriers transmitted from all BSs at the same positions in frequency and time, so at the receiving mobile station, all pilots are superimposed. However, pilot modulating sequences should be unique for each BS. In 802.16e standard, this assumption generally, true for the first (mandatory) zone in the DL frame.

So, at the mobile station, received signal at given pilot subcarrier can be expressed as:

$$\mathbf{x}_r(k) = \mathbf{H}_m(k)\,p_m(k) + \sum_{i=1}^{N\,\mathrm{int}} \mathbf{H}_i(k)\,p_i(k) + n(k)\,, \quad (1)$$

where $\mathbf{x}_r(k)$ – received signal vector of size $1\mathrm{x}N_{rx}$ at all receiving antennas at k-th symbol, $p_m(k)$ and $p_i(k)$ are pilot values for main and interfering base stations respectively, $n(k)$ is residual noise which is modeled as AWGN (we assume that this noise includes background receiver noise and all weak interferers); $\mathbf{H}_m$ is a $1\mathrm{x}N_{rx}$ vector, containing channel transfer functions for the channel from the main BS to the mobile station, $\mathbf{H}_i$ ($i=1..N_{int}$) are channels from the interfering BSs to the considered mobile station. Knowledge of the pilot modulation sequences for interfering sequences may be obtained from the special information element in frame header or, by direct processing of the preamble signal. Matched filtering processing of the downlink preamble, by our results, allows reliable recognition of the several strongest interferers. In practice, the number of interferers can be very large and taking into account all of them will be too computationally complex. Further, by N_{int} we will mean only the limited number of the most powerful interferers, others will be counted in the noise term $n(k)$.

III. Channel Estimation

Most of practical interference cancellation algorithms require knowledge of the interference correlation matrix. Direct estimation of interference correlation matrix at each subcarrier may be a difficult and computationally complex task, which may require averaging over long period of time. Instead, we propose to estimate channel transfer functions for several significant interferers. Then, interference correlation matrix at given subcarrier may be computed as follows:

$$\mathbf{R}_{in} = \sum_{i=1}^{N\,\mathrm{int}} \mathbf{H}_i^H \mathbf{H}_i + \mathbf{I}s_n^2\,, \quad (2)$$

Where $\mathbf{R}_{in}$ is interference correlation matrix $N_{rx}\mathrm{x}N_{rx}$, $\mathbf{I}$ is identity matrix and superscript ^{H} denotes Hermitian transpose.

For practical application to the mobile communications, the channel between BS and MS should be considered non-stationary. With the knowledge of the state-space dynamic model of channel transfer function we can apply apparatus of Kalman filtering to the task of estimation of the main and interfering channels simultaneously. Since Kalman filtering is the recursive procedure that requires matrix operations at each step, the Kalman filter order (matrix dimension) is a critical parameter for the scheme implementation. The total order of the Kalman filter may be fixed to some pre-defined value, and its dimensions may be *adaptively redistributed* between the main and interfering channels to ensure accurate channel tracking. For example, for systems with 2 receive antennas in presence of 2 interfereng BSs the channel state space model of the total order of six can be expressed as follows:

$$\begin{aligned}\mathbf{H}_m(k+1) &= \mathbf{H}_m(k) + \dot{\mathbf{H}}_m(k) + w_m(k)\\ \mathbf{H}_{i1}(k+1) &= \mathbf{H}_{i1}(k) + w_{i1}(k)\\ \mathbf{H}_{i2}(k+1) &= \mathbf{H}_{i2}(k) + w_{i2}(k)\end{aligned} \quad (3)$$

For the case of only one strong interferer, the dimensions can be reallocated correspondingly, ensuring more accurate tracking of one significant interferer. Fast movement of subscriber station will result in rapid changes of the channel transfer function and thus, will require higher- order state space model of the channel transfer function.

Equations (1, 3) comprise the observation model and the state-space model that may be used to construct Kalman filter for channel transfer function estimation. This is common procedure, well described in a number of books [3]. Figure 1 shows step-by-step algorithm for channel transfer estimation. Here **H** and **p** denote generalized vectors – i.e. column vectors with that contain corresponding parameters of the main interferers channels.

Initial conditions:
$\mathbf{H}(0)$: initial estimate of channel state vectore
$\mathbf{V}_H$: a priori estimate covariance,
$\mathbf{V}_n$: observation additive noise covariance,
$\mathbf{V}_w$: signal model noise covariance,
F: transition matrix.
Symbol by symbol recursive filtering consists of the following steps:
Gain update:

$$\mathrm{K(j)} = \mathbf{V_H}(j\,|\,j-1)\mathbf{p}(j)[\mathbf{p}(j)^T\mathbf{V_H}(j\,|\,j-1)\mathbf{p}(j) + \mathbf{V}_n]^{-1}$$

Channel estimate update:

$$\mathbf{H}(j+1) = \mathbf{FH}(j) + \mathrm{K(j)}[\mathrm{x(j)} - \mathbf{p}(j)^T\mathbf{FH}(j)]$$

A posteriori estimate covariance matrix for this step:

$$\mathbf{V_H}(j) = [\mathbf{I} - \mathbf{H}(j)\mathrm{K(j)}]\mathbf{V_H}(j\,|\,j-1)$$

Predict a priori estimate covariance matrix for next step.

$$\mathbf{V_H}(j+1\,|\,j) = \mathbf{FV_H}(j)\mathbf{F}^T + \mathbf{V}_w$$

Figure 1. Kalman filtering recursive procedure

IV. Interference Cancellation

With interference correlation matrix available (2), interference may be cancelled from the received signal using either MMSE or ZF forcing algorithm (4). Note that weights calculation complexity is comparable to the Kalman filtering procedure and most complex blocks, such as matrix inversion can be reused.

$$w = \left(\mathbf{H}_m^H\mathbf{R}_{in}^{-1}\mathbf{H}_m\right)^{-1}\mathbf{H}_m^H\mathbf{R}_{in}^{-1} \quad (4)$$

V. Simulation Results

To evaluate performance of the proposed channel estimation scheme, we have embedded it into 802.16e link-level simulator (DL mode of operation) and simulated using recommended by ITU channel model ITU Pedestrian B [4]. For comparison we have used the simple maximum ratio combining with the simple channel estimation procedure - pilot-based least-square estimator with two-dimensional bilinear interpolation from pilot to the data subcarriers. Figure 2 shows the performance comparison for the conventional technique – maximum ratio combining (MRC) and optimal combining based on the proposed interference correlation matrix measuring procedure through the interfering channels estimation. It can be seen, that in case of 2 interfering BSs proposed scheme gives about 7-8 dB gain. For the case of only one (significant) interfering BS the interference is cancelled out almost completely and the performance limited only by a receiver noise.

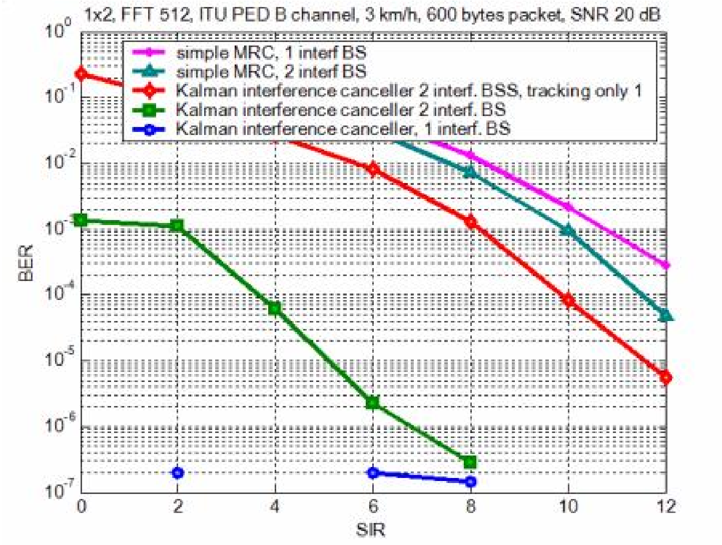

Figure 2. BER vs. SIR perfromamce curver for 2 RX antennas system, variour modes

VI. Summary

The paper presents a new approach to the interference mitigation in the WiMax systems – selective interference cancellation. This approach is applicable to the mobile receivers and allow more accurate channel estimation (for the case of one receive antenna), or interference cancellation (for several receive antennas). Apparatus of Kalman filtering ensure near-optimal solution of the channel estimation problem.

The performance of the proposed methodology was evaluated in the interference envirionment and showed great performance improvement.

References

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