A Joint QR-LS based Coarse-Fine channel estimation and QR-LRL detection For Mobile Wimax 802.16m

Divyang Rawal, Youn-Ok Park, C.Vijaykumar, Hyeong Sook Park, and Hoon Lee

Wireless Packet Modem Division, E.T.R.I., Yuseong-gu 305-350, Daejeon, S.Korea
Email: divyang@etri.re.kr, +82-042-860-1342

Abstract—In this paper, We extended our previous work of QR-RLS based MIMO(Multiple input Multiple output) channel estimation to Mobile Wimax 802.16m system. Mobile wimax system provides high data rate, also fulfills user's requirement like VOD(Video on demand)at very high vehicle speed and also provides better cell coverage area. Channel estimation is crucial part to achieve this goals especially in fast fading environment. Generally, Mobile Wimax systems uses Preamble and Pilots for channel estimation purpose.

In the proposed method both preamble and pilots are jointly used for robust channel estimation. At First, QR-RLS Estimator uses Preamble for coarse channel estimation at start of every frame. Once the coarse channel is estimated, then pilots (scattered throughout time-frequency grid) are jointly used with the coarse channel component to derive the channel fading rate. This fading rate is then used to finely estimate the channel at pilot as well as data subcarrier. Thus robust estimation results without adding any overhead. Jointly estimated channel is then used with QR-LRL based data detection, where hard decision values are calculated. Simulation results are shown under various slow-fast channel fading conditions. Results are compared with pilot based channel estimation with LS(least square) interpolation, which shows that joint coarse-Fine estimation gives better performance.

I. INTRODUCTION

Mobile Wimax refers to telecommunication protocol which provides fixed and mobile internet access at very high speed. It is an IEEE standard for wireless broadband access. Standard IEEE 802.16d has no support for mobility and is thus referred as 'Fixed Wimax’. An amendment of this standard is IEEE 802.16e. Current Wimax revision of this standard provides data rate upto 40Mbits/s, which is still not fulfilling the Video on demand(VOD) requirements for high speed mobiles (max. speed 350 km/hr) and cell coverage 50 km radius. To achieve these requirements Wimax is updated to a new standard 802.16m which is targeted to achieve the above mentioned goals as well as providing data rates upto 1 Gbits/s. IEEE 802.16m uses SofDMA(Scalable Orthogonal frequency division multiple access) as its advanced air interface. Which is an efficient modulation scheme to achieve high data rate transmission over frequency-selective fading channels due to its capability to combat the inter symbol interference (ISI), low complexity, and spectral efficiency. By using Multiple antennas at the Transmitter and Receiver, higher Capacity and diversity gain can be achieved. which is only possible if channel is accurately estimated at the receiver in order to perform coherent detection, space time decoding, diversity combining, and spatial interference suppression.

Various channel estimation methods including two major methods LS(Least-Square) and MMSE(Minimum Mean Square error) [1][2], have been widely used for MIMO-OFDM channel estimation. Also, Different types like Pilot aided/Training based estimation schemes are frequently used for different systems under different channel environments like Fast fading, Flat fading. In such circumstances channel tracking is required to keep a track and estimate mobile environments. To fulfill this necessity many author suggested adaptive channel estimators [3][4]. In [5], author shown that QR-RLS based channel estimator gives better performances in terms of stability, complexity and channel tracking for flat fading channel, which fades frame to frame.

In this paper, we advanced our work [5] by jointly estimating the channel in fast fading environment for Mobile Wimax. The channel is changing from symbol to symbol. To continuously track the channel, pilots are transmitted at regular intervals. Separation between pilots in time-freq grid depends on channel coherence bandwidth(inverse of delay spread) and coherence time (inverse of doppler spread) respectively. These pilots are interpolated using various MMSE-LS methods[1] to find out the channel at data subcarrier. When the pilots used for interpolation are scarce, channel estimation is improper. In [6] author mentioned channel estimation technique based on pilot arrangement in OFDM Systems. In [7] author suggested Coarse and Fine channel estimation for IEEE 802.16d standard, where he combines preamble for coarse estimation, and pilot interpolation (modified LS) for fine estimation. In such cases, pilots in unoccupied resource locations(extra overhead) are also used for channel estimation through transform domain technique, results in more complexity. In the proposed method

1 This work was supported by the IT R&D program of MKE/KEIT, [K1002143, Development of IMT-Advanced based WiBro Platform Technologies].
some changes are applied. Preamble based coarse channel estimation is done using QR-RLS method at every frame. Once the coarse channel is estimated, pilots(scattered throughout time-frequency grid) are combined with Coarsely estimated channel to derive channel fading parameter from symbol to symbol. This fading parameter is then applied to find the channel at data subcarrier in every symbol.

The remainder of this paper is organized as follows. IEEE 802.16m frame structure and estimation requirements are described in section II. In section III, the MIMO OFDM system model with multipath fading channel is shown. Section IV discusses error minimization criteria. Section V gives description about proposed QR-LS based joint coarse-fine estimation is done using QR-RLS method at every frame. Once

receive antenna, and thus 4 streams of data, so maximum pilots available for interpolation for 1 stream within an allocated PRU is 4 as shown in Fig.(2). We cannot use adjacent PRU Pilots of the same stream for interpolation because it may be empty. Also if we consider high fading rate, in which channel changes symbol to symbol, interpolation in time direction doesn’t make sense.

On the other hand, as mentioned every frame starts with Advanced-preamble PA/SA[8]. For every antenna, it contains non-overlapping subcarriers, the rest contains null subcarriers, so preamble cannot estimate the channel at each and every subcarrier in freq. domain.

To mitigate the above mentioned case, In this paper QR-RLS based channel estimator uses preamble in time domain to estimate coarse component of channel, which is then transformed to freq. domain and used with pilots to finely track the channel fading parameter from symbol to symbol. This estimated fading parameter is then used for estimating the channel at each point in the subframe.

III. MIMO System Model

A general MIMO system model with $N_t$ Transmit, $N_r$ receive antennas is shown in Fig.(3). $X_1, X_2, X_3,...,X_{N_t}$ represents respective input signals to $N_t$ input antennas, where

$$X_p = [x_{(p,n)}, x_{(p,n+1)}, ... x_{(p,n+N_s-1)}]$$

at time n, with $N_s$ data symbols. For making analysis simple consider $N_t = N_r$. The multipath time variant channel between $p^{th}$ transmit and $q^{th}$ receive antenna with L resolvable paths is given by

$$h_p(t) = \sum_{n=0}^{L-1} \beta_{pq}(l) \cdot \delta(t - T_l)$$

where

$$\beta_{pq}(l) = \alpha_{pq}(l) \cdot e^{j\phi(l) + 2\pi f(D,l)t}$$

where $\alpha_{pq}, \phi(l)$ and $f(D,l)$ denote the amplitude, phase and the doppler shift of the l/th path, respectively. Assuming isotropic scattering, the autocorrelation of the path gains as shown in[10] is

$$r_l(t) = E[\beta^*_l(t)\beta_l(t+\tau)] = \sigma_l^2 J_0(2\pi f_{Dmax}\tau)$$

where $\sigma_l^2$ is the power of the l/th path gain, $J_0(x)$ is the bessel function of the first kind of order 0, and $f_{Dmax}$ is the
maximum Doppler frequency which is related to the velocity $v$ of movement and the wavelength $\lambda$ of the carrier frequency $f_{D_{\text{max}}} = v / \lambda$.

The received signal $Y$ at time $n$, in square matrix form having dimension $[(Nt \cdot L) \times (Nt \cdot L)]$ can be expressed as

$$Y(n) = (U(n) \cdot H(n)) + V(n) \quad (4)$$

where matrix $U(n)$ is prewindowed matrix of $[(Nt \cdot L) \times (Nt \cdot L)]$ having $Nt \cdot L$ data symbols from each Tx. antenna at time instant $n$, and

$$H(n) = [H_1(n), H_2(n), ... H_{Nt}(n)]$$

where $H_q(n)$ is

$$H_q(n) = [H_{(1,q)}(n), H_{(2,q)}(n)...H_{(Nt,q)}(n)]^T$$

and $H_{(p,q)}(n)$ is

$$H_{(p,q)}(n) = [h_{pq}(n,0), h_{pq}(n,1), ..., h_{pq}(n, L-1)]^T$$

$V$ is $[(Nt \cdot L) \times (Nt \cdot L)]$ with complex elements that are independent and identically distributed (i.i.d.) Gaussian random variable with zero mean and variance $\sigma_v^2$.

IV. ERROR MINIMIZATION CRITERIA FOR MIMO CHANNEL ESTIMATION

Each transmitter transmits Preamble as first OFDM symbol. Channel is estimated during this training period, where estimated channel is $\bar{H}$.

Consider the received signal at $q^{th}$ receive antenna represented in matrix form as

$$Y_q(n) = (U(n) \cdot H_q(n)) + V_q(n) \quad (5)$$

The posteriori error is given by the difference between the received preamble symbol and it’s corresponding estimate at time $n$ on $q^{th}$ receiving antenna

$$e(q, n) = y(q, n) - \bar{y}(q, n) \quad (6)$$

$$e(q, n) = y(q, n) - Xpre(n) \cdot \bar{H} \quad (7)$$

Where $\bar{H}$ has the same dimensionality as $H$. The Weighted Least square error at time $n$ is given by

$$\zeta(n) = \sum_{i=0}^{n} \lambda^{n-i} |e(q, i)|^2, \quad (8)$$

where $\lambda$ is forgetting factor, whose value lies between $(0,1)$ depending on channel fading conditions. Solution of the above equation gives the optimum value for the estimated channel coefficients $H$ at time $n$. The optimum solution of Eq.(8) is given by[11]

$$\bar{H}(n) = R_{X^{-1}}(n) \cdot R_{YX} \quad (9)$$

where $R_X = (U^T U) = Xpre^T Xpre$ is the autocorrelation matrix of the Preamble signal, and $R_{YX}$ is the cross correlation matrix between received signal and the preamble signal at time $n$.

V. JOINT QR-LS BASED COARSE-FINE CHANNEL ESTIMATOR

A. QR-RLS based coarse channel estimator

Channel $H(n)$ at preamble symbol is derived using QR-RLS estimator by applying QR decomposition to eq.(9), which is described fully in [5]. After estimation let the estimated channel at preamble symbol is designated as $\bar{H}_{\text{pre}}(n)$ from eq.(9).

B. Pilot based fine estimation

As mentioned previously, PRU is the smallest resource allocation unit in a subframe, which contains data as well as pilot subcarriers. Let the no. of data burst transmitted in a subframe is $Nd$. Within a subframe $Nd$ data burst is allocated in $Np$ PRUs. Therefore pilots per subframe per stream are $Nd * Np$. For simplicity we considered $Nt = Nr = 4$, and no. of data stream is also 4. Pilots per PRU per data stream is 4 as shown in fig.(4)[8]. Since we referenced the Frame preamble symbol at time $n$, then OFDM symbols will occur at time $n+1, n+2, n+3, ...$. Let the $Xp_{qk}(n+1)$ and $Y_{p_{qk}}(n+1)$ denote the transmitted and received pilot subcarriers at time $n+1$ at $q^{th}$ antenna and $k^{th}$ subcarrier. Then the channel estimate at time $n+1$ is given by

$$\bar{H}p_{qk}(n+1) = Xp_{qk}(n+1) / Y_{p_{qk}}(n+1) \quad (10)$$

Also $\bar{H}_{\text{pre}}(n)$ denote the estimated channel at the $q^{th}$ antenna at preamble symbol at time $n$. By using eq.(10) with this we can derive fading parameter $Dop_{sa}$ at time $n+1$ as...
\[ D_{op_a}(n+1) = \frac{4}{(N_d \cdot N_p)} \sum_{i=0}^{(N_d + N_p) - 1} \frac{\bar{H}_{p,q_k}(n+1)}{\bar{H}_{pre,q_k}(n)} \]  

(11)

Using above eq.(11), Channel at every subcarrier at time \( n + 1 \) is calculated as follows,

\[ \bar{H}_{pre,q}(n+1) = D_{op_a}(n+1) \cdot \bar{H}_{pre,q}(n) \]  

(12)

Similarly, Channel is estimated throughout the whole frame until the next preamble. Estimated channel is then used for data detection using QR-LRL algorithm, which is fully explained in ref.[10]. Hard decision values are considered for simulation results.

VI. SIMULATION RESULTS

Simulation results are shown here for \( N_t = N_r = 4 \), but it can be generalized for any no. of Tx. as well as Rx. cases. The channel is considered approx. constant for OFDM symbol duration, changes symbol to symbol. Simulation parameters:

- Frame size : 8 subframe
- OFDM symbols per subframe : 5
- First Symbol of each frame is Preamble symbol
- FFT size : 2048
- Fs : 22.4 MHz
- fc : 2.5849 Ghz
- Channel profile : Ped-A 5 Km/Hr, Veh-A 240 Km/Hr, Veh-B 120 Km/Hr
- Modulation Type : QPSK,16-QAM

In simulation results, Pilot based linear interpolation method is compared with the proposed method. Pilots linearly estimates the channel by using available pilots per PRU per data stream which is 4 for one PRU (Fig.(2)). Fig.(5-10) shows the MSE error and Ber performance for three different fading scenarios mentioned below.

1) Ped-A channel:

The channel fades slowly, so MMSE error shows constant difference between the proposed method, which comes from the coarse component estimation. BER results shows not much difference in both methods, still proposed method gives
better BER performance at high SNR. The modulation type
considered is QPSK.
2) Veh-A, Veh-B channel:
Channel fades at very high speed. Results shows that once
Coarse estimation is done, then Fine tracking of the channel
makes much difference in MMSE as well as BER results. The
modulation type considered is 16-QAM.

VII. CONCLUSION

Simulation results show that joint QR-LS based Coarse-
fine channel estimator performs better estimation compared to
pilot-interpolation based estimation. BER graphs also shows
that proposed estimation method outperforms pilot-LS based
method in fast fading environment with slight increase in
computational complexity required for QR-RLS based coarse
channel estimator.

REFERENCES
in a fading environment when using multiple antennas”, Wireless Press.
Tracking Dispersive Channels in MIMO OFDM Systems”, IEEE Conf.
Tracking of Linear Time-Variant Systems by Extended RLS Algorithms”,
[5] D Rawal, Park Youn Ok, C. vijaykumar, “A Novel Training based QR-
RLS channel estimator for OFDM-MIMO systems”, WiAd-2010,IEEE
Estimation Techniques Based on Pilot Arrangement in OFDM Systems”,
[7] Xuetao Dong, Xianzhong Xie,Xin chen, “Joint channel estimation for
WiMax by Preamble and uneven Pilots”, Wireless Communications,
(Draft-D10)”.
2008
1974.