

Estimation of Uplink Channel for Multi-user LTE System in High-Speed Environment

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ABSTRACT—: *This paper presents a novel estimation technique for the uplink channel of long-term evolution (LTE) system in high-speed environment without increasing any spectral overhead. With high terminal velocity, the time-varying channels being encountered making its coherence time is small enough to be compared with symbol duration. Hence a severe degradation in estimation process is being registered with conventional frame structure of LTE system where pilot symbols are introduced in each 0.5ms. This paper has proposed a frequency domain estimation updating algorithm to track the time-varying channel parameters and generate updated estimates in each payload symbol without any additional spectral overhead. A significant improvement in system performance in high-speed environment is registered.*

Keywords— Multi-user LTE, SC-FDMA, High-speed environment, Channel estimation, estimation updating algorithm.

1. INTRODUCTION

In uplink of multi-user LTE system, several user equipments (UEs) send their data packets to the access point (AP) sharing same single carrier frequency division multiple access (SC-FDMA) symbols. SC-FDMA modulation is the defined standard for uplink of LTE system; preferred over orthogonal frequency division multiplexing (OFDM) due to its lower peak to average ratio (PAPR) value [1]. To enhance in link capacity, the physical layer of LTE system employs multiple input multiple output (MIMO) based system where both UE and AP are equipped with multiple antenna elements [2, 3]. This paper addresses the problem of the channel estimation process in the uplink of multi-user LTE system for time-varying channels encountered in high-speed environment. The current and accurate information of channel state at the detection end is essential for the reliable system performance that includes the complex scaling factor of each sub-carrier. In a MIMO system with the number of antenna present with UE and AP are N_T and N_R respectively, the number of parameters associated with the estimation process increases ($N_T \times N_R$) folds as compared to the conventional SISO system. With limited resource allocated, the channel estimation process has to deal with the issues like transmit diversity, computational complexity and memory space requirement for estimation process. The uplink channel in LTE system is estimated by block type reference signal (pilots); the uplink frame structure has sub-frames of duration 1ms, consists of 14 SC-FDMA symbols. The fourth and the 11th SC-FDMA symbols are used for estimation of CSI using block type reference signals. The estimations obtained in those symbols are utilized for intermediate payload symbols by considering channel fading process is highly correlated over time axis for several SC-FDMA symbol durations [4]. Though two block-type pilot symbols per sub-frame are sufficient enough to estimate the CSI with high degree of accuracy in static and quasi-static channels, fast time-varying channels is encountered in high-speed wireless applications. The coherence time of such type of channels is small enough to be compared with symbol duration and the channel cannot be considered as static over entire frame duration. The instantaneous channel capacity is inversely related to time rate of change in channel parameters i.e. velocity of user equipment (UE). Inter-symbol time-selective fading is introduced causing severe error in estimation process [5]. As LTE supports high mobility of UE, the estimation of time-selective channel is a challenging problem.

The estimation of time-varying channel is addressed in literature with time-domain estimation approach. In [6], Kalman filtering and polynomial fitting based time-domain estimation is proposed which follows FD-LS estimation. However, the performance is burdened with high computational complexity due to tracking of time-domain channel impulse response. In [7], basis-expansion model (BEM) is proposed where channel is modeled with basis-expansion parameters and the time-variation is tracked with window based approach. The size of the window depends on Doppler shift of the channel; hence the exact estimate of Doppler shift is essential at receiver which

adds computational overhead in practical scenario. A low complexity transform domain polynomial BEM (PBEM) based model for fast time-varying channel is proposed in [8]. However, the auto regressive (AR) approach requires a huge memory space and the complexity of the method depends on the initial DFT size and number of coefficient used for modeling the channel. In [9], method is proposed to use 33% lesser coefficient to model the channel nearly same accuracy. However, the complexity to the system remains in higher side with number of parameters involved in MIMO system and the transform of time domain CSI to frequency domain for equalization. A semiblind estimation technique of MIMO channel for single-carrier system is presented in [10] that suite in static and quasi-static channels only not in time-varying channel. A low complexity duplex model for multi-user system where the UEs are equipped with single antenna element in high-speed environment has been discussed in [11].

To track the time-varying channel parameters of LTE uplink system in high-speed environment, this paper proposes a novel frequency domain estimation updating algorithm. The algorithm tracks the dynamics of the channel caused due to relative motion between UE and AP by exploiting the correlation of channel gains of successive sub-carriers in frequency axis and generates updated estimates in each payload symbol. Moreover, unlike BEM based methods proposed in literature, the proposed estimation updating algorithm does not require the estimate of the frequency offset due to Doppler shift to track the time-varying channel parameters. The organization of the paper is as follows, the uplink model for LTE-A system is given in section 2, the proposed channel estimation model is given in section 3, the simulation results are presented in section 4 and section 5 concludes the paper.

Notations: Throughout the paper, the vectors are denoted as boldfaced \mathbf{A} and matrices as boldfaced with curly bracket $\{\mathbf{A}\}$. This paper uses $\{\mathbf{A}\}^H$ and $\det(\{\mathbf{A}\})$ to denote the complex transpose and determinant respectively of the matrix $\{\mathbf{A}\}$.

2. UPLINK MODEL FOR MULTI-USER LTE SYSTEM

Consider a multi-user system where U number of UEs transmitting data packets to the AP through same SC-FDMA symbol of M sub-carriers. Let each UE as well as the AP are equipped with N_T antenna elements where each sub-carrier carries equal numbers of independent information symbols. The payload data string of each user is spreaded over N sub-carriers ($N=M/U$) and mapped into the SC-FDMA symbol through localized mapping. Let $d_{(u,l)}^n(p)$ is the p -th element of modulated input data vector of size N where the subscripts u and l are the indexes of UE and the antenna in it respectively and the superscript n is the SC-FDMA symbol index in the sub-frame. The frequency domain signal for k -th sub-carrier is

$$X_{(u,j)}^n[k] = \Gamma_{(u)} \left[\frac{1}{\sqrt{N}} \sum_{p=0}^{N-1} d_{(u,l)}^n(p) \exp(-j2\pi p k / N) \right], \quad (1)$$

where $\Gamma_{(u)}[\]$ is the sub-carrier mapping function for u -th UE. The frequency-domain signal received at i -th antenna of eNodeB is

$$Y_i^n[k] = \sum_{u=1}^U \sum_{j=1}^{N_T} H_{i,(u,j)}^n[k]. X_{(u,j)}^n[k] + Z_i^n[k]. \quad (2)$$

Here $H_{i,(u,l)}^n[k]$ is the time-varying gain associated with the k -th sub-carrier of the channel between l -th antenna of u -th UE and i -th antenna of AP and $Z_i^n[k]$ is the corresponding frequency domain additive noise. As the sub-carrier mapping function are orthogonal to each other, the received signal for k -th sub-carrier is the response of any one of U users. Hence equation (2) is reduced to

$$Y_i^n[k] = \sum_{l=1}^{N_T} H_{i,(u,l)}^n[k]. X_{(u,l)}^n[k] + Z_i^n[k]. \quad (3)$$

The received signal vector for k -th sub-carrier

$$\mathbf{Y}^{n,k} = \{\mathbf{H}^{n,k}\} . \mathbf{X}^{n,k} + \mathbf{Z}^{n,k}, \quad (4)$$

where $\{\mathbf{H}^{n,k}\}$, $\mathbf{X}^{n,k}$ and $\mathbf{Z}^{n,k}$ are the time-varying channel matrix, transmitted signal vector and noise vector for k -th sub-carrier respectively. With knowledge of channel transfer function at receiving end, the signal vector is detected as

$$\hat{\mathbf{X}}^{n,k} = \{\mathbf{W}^{n,k}\} \cdot \mathbf{Y}^{n,k} \quad (5)$$

where $\{\mathbf{W}^{n,k}\} = [\{\hat{\mathbf{H}}^{n,k}\}^H \cdot \{\hat{\mathbf{H}}^{n,k}\}]^{-1} \cdot \{\hat{\mathbf{H}}^{n,k}\}^H$ and $\{\hat{\mathbf{H}}^{n,k}\}$ is the estimate of $\{\mathbf{H}^{n,k}\}$. The l -th entry of the detected signal vector $\hat{X}_{(u,l)}^n[k]$ is corresponds to l -th antenna of u -th UE considering k -th sub-carrier is corresponds to u -th UE. The corresponding un-spreaded time domain is given by

$$\hat{d}_{(u,l)}^n(p) = \Gamma_{(u)}^{-1} \left[\frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} \hat{X}_{(u,l)}^n[k] \exp(j2\pi pk/N) \right], \quad (6)$$

where $\Gamma_{(u)}^{-1}[\cdot]$ is the sub-carrier de-mapping function for u -th UE.

3. PROPOSED ESTIMATION MODEL

In uplink of LTE-A system, block type reference symbols are introduced in every 0.5ms. In the proposed estimation model, FD-LS estimation is made in the reference symbols using frequency domain orthogonal reference signals followed by proposed estimation updating algorithm to track the time-varying channel parameters in each intermediate payload block.

(A) FD-LS estimation

The reference signal generated by each transmitting antenna maintains frequency domain orthogonality among each other by interleaving nulls with reference bits [12]. Hence equation (3) is reduced to

$$Y_i^n[k] = H_{i,(u,l)}^n [k] \cdot X_{(u,l)}^n [k] + Z_i^n [k] \quad (7)$$

Considering n -th symbol is the slot for reference signal, the gain at the k -th sub-carrier of channel between l -th antenna of u -th UE and i -th antenna of AP during n -th block is estimated by FD-LS estimation given by

$$\hat{H}_{i,(u,l)}^n [k] = \frac{Y_i^n [k] \cdot (X_{(u,l)}^n [k])^*}{|X_{(u,l)}^n [k]|^2} \quad (8)$$

Here $\hat{H}_{i,(u,l)}^n [k]$ is the $(i;l)$ -th entry of $\{\hat{\mathbf{H}}^{n,k}\}$. The complete channel transfer function (CTF) is estimated by interpolating the information obtained in equation (8).

(B) Proposed Estimation updating algorithm

The time fluctuation of a channel may considered as a random process; the correlation between temporal CTF during n -th and $(n+t)$ -th symbol is given as,

$$\rho(t) = \frac{E[\mathbf{H}^{n,k} \cdot (\mathbf{H}^{n+t,k})^*]}{E[(\mathbf{H}^{n,k})^2]}, \quad (9)$$

where t is the index of SC-FDMA symbol after reference symbol and $E[\cdot]$ is the ensemble expectation operation. The value of $\rho(t)$ decreases with increase of t . The time-rate of change is directly proportional to the Doppler shift in carrier which is a linear function of velocity of UE. Hence in high-speed environment, the channel cannot be considered to be strongly correlated for intermediate symbols. The proposed estimation updating algorithm generates updated estimates

for each payload symbol by utilizing the hard detected information signal of previous symbol. Let $\tilde{d}_{(u,l)}^n(p)$ be the hard-detected signal form of $\hat{d}_{(u,l)}^n(p)$, which are used by the proposed updating algorithm to generate an updated estimate for $(n+1)$ -th symbol. For frequency domain processing, the hard-detected signal present in transform domain has to be brought into frequency domain as

$$\tilde{X}_{(u,l)}^n[k] = \Gamma_{(u)} \left[\frac{1}{\sqrt{N}} \sum_{p=0}^{N-1} \tilde{d}_{(u,l)}^n(p) \exp(-j2\pi pk/N) \right]. \quad (10)$$

As in high-speed environment the statistics of channel fading is anticipated as Rician with a strong line-of-sight component [13]. Hence to resolve the transmit diversity problem, the updating algorithm exploits the correlation in channel gains of successive sub-carriers in frequency axis. The algorithm assumes there is a strong correlation between channel gains of N_T successive sub-carriers. Hence considering the set of sub-carrier of index $[k + q_{\min}, k + q_{\max}]$ are used by u -th UE, we have

$$H_{i,(u,j)}^n[k+q] \cong H_{i,(u,j)}^n[k], \quad \forall q \in [q_{\min}, q_{\max}]. \quad (11)$$

For odd values of N_T , $q_{\min} = (1 - N_T)/2$, $q_{\max} = (N_T - 1)/2$ and for even values, $q_{\min} = 1 - (N_T/2)$, $q_{\max} = N_T/2$. With this assumption, the frequency domain received signal of $(k+q)$ -th sub-carrier during n -th block at i -th receiver is given by

$$Y_i^n[k+q] = \sum_{j=1}^{N_T} H_{i,(u,j)}^n[k] \cdot \tilde{X}_{(u,l)}^n[k+q] + Z_i^n[k+q]. \quad (12)$$

To estimate the gains of k -th sub-carrier of all the channels associated with i -th receiving antenna, the updating algorithm goes for joint processing of N_T successive sub-carriers. In vector notation we have,

$$\hat{\mathbf{Y}}_i^{n,k} = \{ \hat{\mathbf{X}}_u^{n,k} \} \cdot \hat{\mathbf{H}}_i^{n,k} + \hat{\mathbf{Z}}_i^{n,k}. \quad (13)$$

Here,

$$\begin{aligned} \hat{\mathbf{Y}}_i^{n,k} &= [Y_i^n[k+q_{\min}] \cdots Y_i^n[k] \cdots Y_i^n[k+q_{\max}]]^H, \\ \hat{\mathbf{H}}_i^{n,k} &= [H_{i,(u,1)}^n[k] \cdots H_{i,(u,l)}^n[k] \cdots H_{i,(u,N_T)}^n[k]]^H, \\ \{ \hat{\mathbf{X}}_u^{n,k} \} &= [\hat{\mathbf{x}}_{(u,1)}^{n,k} \cdots \hat{\mathbf{x}}_{(u,l)}^{n,k} \cdots \hat{\mathbf{x}}_{(u,N_T)}^{n,k}], \\ \hat{\mathbf{x}}_{(u,l)}^{n,k} &= [\tilde{X}_{(u,l)}^n[k+q_{\min}] \cdots \tilde{X}_{(u,l)}^n[k] \cdots \tilde{X}_{(u,l)}^n[k+q_{\max}]]^H, \\ \hat{\mathbf{Z}}_i^{n,k} &= [Z_i^n[k+q_{\min}] \cdots Z_i^n[k] \cdots Z_i^n[k+q_{\max}]]^H. \end{aligned}$$

The estimate of gain vector of the k -th sub-carriers associated with all channels related to i -th antenna of AP is obtained by solving the given LS estimation problem:

$$\hat{\mathbf{H}}_i^{n,k} = \arg \min_{\mathbf{H}_i^{n,k}} \left\| \hat{\mathbf{Y}}_i^{n,k} - \{ \hat{\mathbf{X}}_u^{n,k} \} \cdot \mathbf{H}_i^{n,k} \right\|^2. \quad (14)$$

Hence, the solution of channel gain between the j -th antenna of u -th UE and i -th antenna of eNodeB associated with k -th sub-carrier, during the n -th block is given by

$$\hat{H}_{i,(u,l)}^n[k] = \frac{\det(\{ \hat{\mathbf{X}}_{i,(u,l)}^{n,k} \})}{\det(\{ \hat{\mathbf{X}}_u^{n,k} \})}. \quad (15)$$

Here $\{ \hat{\mathbf{X}}_{i,(u,l)}^{n,k} \}$ is another matrix associated with l -th antenna of u -th UE and i -th antenna of AP is given by

$$\{\widehat{\mathbf{X}}_{i,(u,l)}^{n,k}\} = \{\widehat{\mathbf{X}}_u^{n,k}\} \Big|_{\widehat{\mathbf{x}}_{(u,l)}^{n,k} = \widehat{\mathbf{y}}_i^{n,k}}, \quad \forall i, l. \quad (16)$$

An abnormal solution of (15) is obtained when $|\det(\{\widehat{\mathbf{X}}_u^{n,k}\})| \leq \varepsilon$, as ε is a very small positive quantity. For above condition, for any k-th sub-carriers, the algorithm skips the estimation for that sub-carrier and the estimates of (k-1)-th sub-carrier are considered. During simulation, the algorithm considers $\varepsilon = 0.001$. The estimate of the channel gains obtained is utilized in the next SC-FDMA symbol for channel equalization and interference cancellation. Considering the n-th symbol is being used for reference signal, the mean squared error (MSE) in estimation process in (n+t)-th symbol ($t < 7$) is

$$MSE^{n+t} = E[(\mathbf{H}^{n+t} - \widehat{\mathbf{H}}^{n+t})^H (\mathbf{H}^{n+t} - \widehat{\mathbf{H}}^{n+t})], \quad (17)$$

where \mathbf{H}^{n+t} and $\widehat{\mathbf{H}}^{n+t}$ are true and estimated CTF for (n+t)-th symbol. As in high-speed environment the channel shows fast time-varying property, $E[\widehat{\mathbf{H}}^{n+t} - \widehat{\mathbf{H}}^{n+t-1}] \leq E[\widehat{\mathbf{H}}^{n+t} - \widehat{\mathbf{H}}^n]$ resulting $MSE_{\text{Proposed}}^{n+t} \leq MSE_{\text{FD-LS}}^{n+t}$.

4. SIMULATION RESULTS

In this section, the performance of the proposed estimation model for time-varying channel, encountered in high-speed environments, is investigated through simulation. The type-1 frame structure of LTE, defined in 3GPP, is considered [4, 14]. The channel model used for verification of performance is 9 tap Extended Vehicular A model (EVA) [15-16]. The details of parameters used for simulation are given in table-1.

TABLE-1 SIMULATION PAREMETERS

Parameters	
Air Interface	SC-FDMA
Carrier Frequency	2 GHz
Modulation Type	QPSK
Number of UE in multi-user system	08
Number of antenna in each UE	02
Number of antenna in AP	02
Number of total sub-carrier	1024
Length of cyclic prefix	16
Number of sub-carrier per user	128
Mapping Method	Localized Mapping
Channel Model	9 tap Extended Vehicular A
Rician K-factor	10
Velocity of UE	150, 300 & 450 km/h
50% Coherence time of channel	0.65ms, 0.32ms & 0.21ms
Inter reference symbol gap	7 symbols (0.5ms)

The performance of estimation updating algorithm is analyzed in Fig. 1 which shows the mean squared error in estimation for successive payload symbols after reference block at signal to noise ratio (SNR) level of 25dB. In the conventional FD-LS model, the estimation degrades in successive symbols as the CTF estimated by reference signal is utilized during all intermediate payload blocks. Whereas in the proposed estimation model, the estimate remains relatively flat down the successive symbols as the estimate updating algorithm updates the estimate of time-varying channel parameters in each payload symbol. In simulation, there is marginal degradation of MSE in estimation for proposed model has been observed which is due to error propagation as the estimation update is based on the hard-detected payload symbol.

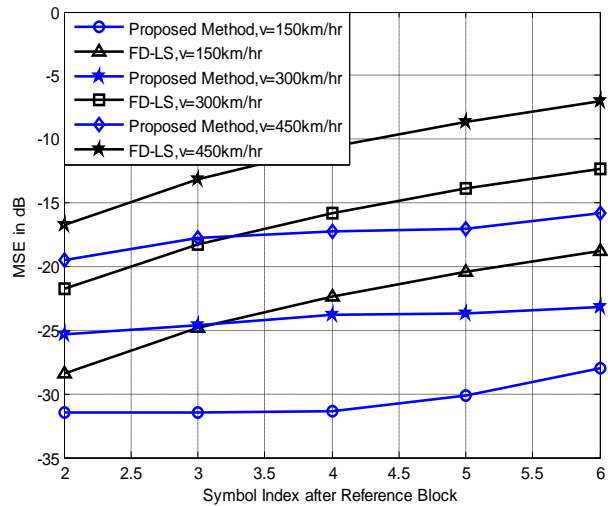


Fig. 1 Mean squared error (MSE) in estimation process in successive symbols after reference block at SNR=25dB

The performance comparisons in terms of quality of service (QoS) parameters between the presented model which adopts estimation updating algorithm and the FD-LS scheme is presented. The Fig. 2 and Fig. 3 present the performance of mean square error (MSE) in channel estimation process and the uncoded bit error rate (BER) performance respectively of both models. From both the figures it is clear that, the proposed model out performs the compared model with the absence of updating algorithm; the QoS parameters of proposed model is significantly lower in all steps than those of FD-LS model.

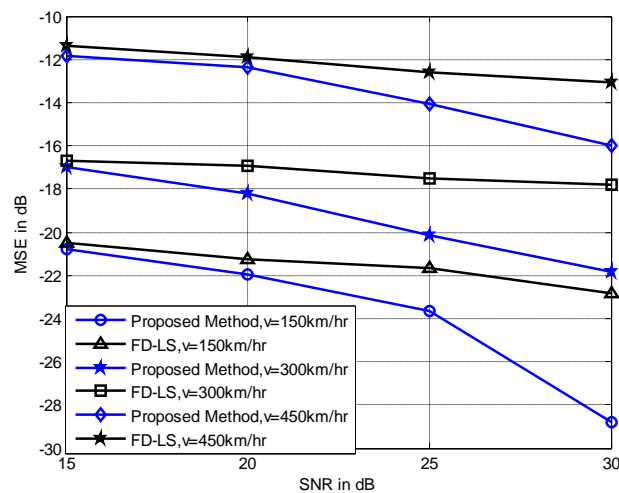


Fig. 2 Performance of MSE in channel estimation process

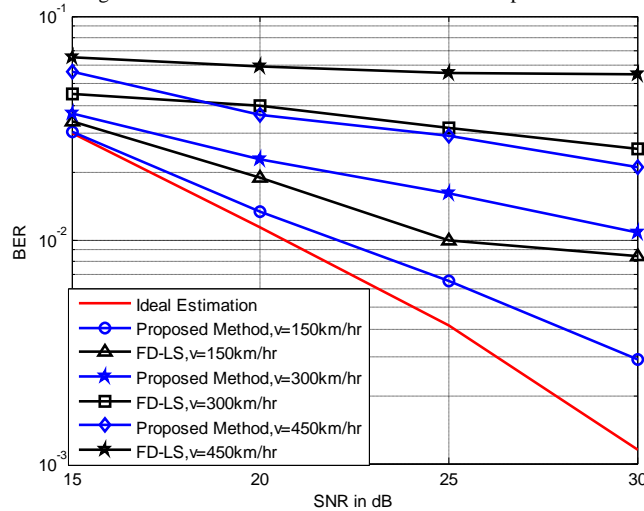


Fig. 3 Performance of bit error rate (BER) of un-coded signal

5. CONCLUSIONS

This paper presents a novel channel estimation model for uplink of multi-user LTE network well-suited in high-speed environment. This paper proposes a frequency domain low complexity estimation updating algorithm which tracks the dynamics of channel and provides the updated estimate in each payload symbol. For the proposed estimation updating algorithm, the *a priori* information about frequency offset is not essential. Without increasing the spectral overhead, a significant improvement in system performance in high-speed environment is registered.

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