Channel Estimation Scheme for 3.9G Wireless Communication Systems Using RLS Algorithm

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***Abstract*—Main challenges for a terminal implementation are efficient realization of the receiver, especially for channel estimation (CE) and equalization. In this paper, training based recursive least square (RLS) channel estimator technique is presented for a long term evolution (LTE) single carrier-frequency division multiple access (SC-FDMA) wireless communication system. This CE scheme uses adaptive RLS estimator which is able to update parameters of the estimator continuously, so that knowledge of channel and noise statistics are not required. Simulation results show that the RLS CE scheme with 500 Hz Doppler frequency has 3 dB better performances compared with 1.5 kHz Doppler frequency.**

***Keywords*— Channel estimation, RLS, SC-FDMA.**

I. INTRODUCTION

The 3rd generation partnership project (3GPP) members started a feasibility study on the enhancement of the universal terrestrial radio access (UTRA), to improve the mobile phone standard to cope with future requirements. This project was called long term evolution (LTE) [1],[2]. LTE uses orthogonal frequency division multiple access (OFDMA) for downlink and single carrier-frequency division multiple access (SC-FDMA) for uplink transmission [1]. A highly efficient way to cope with the frequency selectivity of wideband channel is OFDMA. OFDMA is an effective technique for combating multipath fading and for high bit rate transmission over mobile wireless channels. Channel estimation (CE) has been successfully used to improve the performance of the LTE OFDMA systems. It can be employed for the purpose of detecting received signal, improve signal-to-noise ratio (SNR), channel equalization, cochannel interference (CCI) rejection, and improved the system performance [3-5]. The training CE algorithm requires probe sequences; the receiver can use this probe sequence to reconstruct the transmitted waveform [6-8]. Training symbols can be placed either at the beginning of each burst as a preamble or regularly through the burst. Training sequences are transmitted at certain positions of the SC-FDMA frequency time pattern, in its place of data.

Adaptive CE has been, and still is, an area of active research topics, playing imperative roles in an ever growing number of applications such as wireless communications where the channel is rapidly time-varying. Signal processing techniques that use recursively estimated, time varying models are normally called adaptive. Different adaptive CE algorithms have been proposed over the years for the purpose of updating the channel coefficient. The least mean square (LMS) method, its normalized version (NLMS), the affine projection algorithm (APA), as well as the recursive least square (RLS) method are well known examples of such CE algorithms. The well known LMS/NLMS CE algorithms are attractive from a computational complexity point of view but their convergence behavior for highly correlated input signals is poor. The RLS CE method resolves this trouble, but at the expense of increased complexity. A very large number of fast RLS CE methods have been developed over the years, but regrettably, it seems that the better a fast RLS CE method is in terms of computational efficiency and numerical stability. In addition, the RLS algorithm has the recursive inversion of an estimate of the autocorrelation matrix of the input signal as its cornerstone, problems arise, if the autocorrelation matrix is rank deficient.

In this paper, we analysis the adaptive RLS CE method in the LTE SC-FDMA systems. This CE method uses adaptive estimator which is able to update parameters of the estimator continuously. Simulation results show that the RLS CE scheme with 500 Hz Doppler frequency has 3 dB better performances compared with 1500 Hz Doppler frequency.

We use the following notations throughout this paper: bold face lower letter is used to represent vector. Superscripts $\mathbf{x}^*$ and $\mathbf{x}^T$ denote the conjugate and conjugate transpose of the complex vector **x** respectively.

The remainder of the paper is organized as follows: section II describes wireless system model. The RLS CE scheme is presented in section III, and its performance is analyzed in section IV. Finally, some concluding remarks are given in section V.

II. WIRELESS COMMUNICATION SYSTEMS

Nowadays, cellular mobile phones have become an important tool and part of daily life. In the last decade, cellular systems have experienced fast development and there are currently about two billion users over the world. The idea of cellular mobile communications is to divide large zones into small cells, and it can provide radio coverage over a wider area than the area of one cell. This concept was developed by researchers at AT & T Bell laboratories during the 1950s and 1960s. The initial cellular system was created by nippon telephone & telegraph (NTT) in Japan, 1979. From then on, the cellular mobile communication has evolved.

The mobile communication systems are frequently classified as different generations depending of the service offered. The first generation (1G) comprises the analog communication techniques, and it was mainly built on frequency modulation (FM) and frequency division multiple accesses (FDMA). Digital communication techniques appeared in the second generation (2G) systems, and main access schemes are time division multiple access (TDMA) and code division multiple access (CDMA). The two most commonly accepted 2G systems are global system for mobile (GSM) and interim standard-95 (IS-95). These systems mostly offer speech communication, but also data communication limited to rather low transmission rates. The concept of the third generation (3G) system started operations on October, 2002 in Japan. The 3GPP members started a feasibility study on the enhancement of the universal terrestrial radio access (UTRA) in December 2004, to improve the mobile phone standard to cope with future requirements. This project was called LTE. 3GPP LTE uses SC-FDMA for uplink transmission and OFDMA for downlink transmission. Fig. 1 summarizes the evolution path of cellular mobile communications systems.

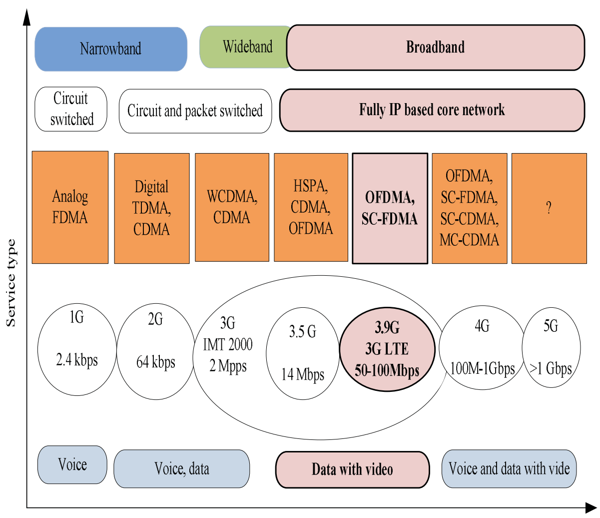

Fig. 1. Evolution path in mobile communication systems.

A simplified block diagram of the LTE SC-FDMA transceiver is shown in Fig. 2.

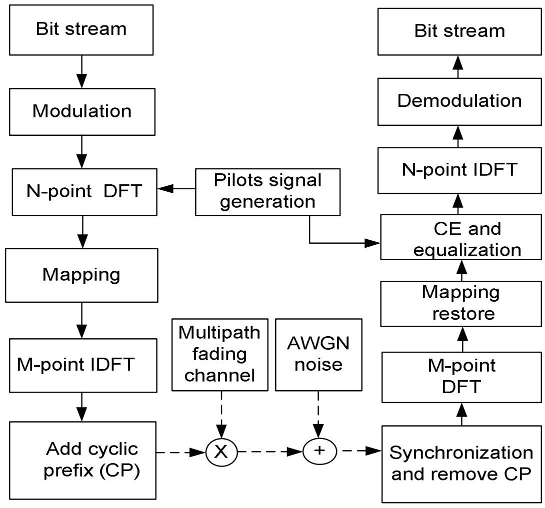

Fig. 2. LTE SC-FDMA transceiver system model.

At the transmitter side, a baseband modulator transmits the binary input to one of several possible modulation formats including binary phase shift keying (BPSK), quandary PSK (QPSK), 8 level PSK (8PSK), 16-QAM, and 64-QAM. CE is often achieved by multiplexing known symbols, so called, pilot symbols into data sequences [1]. These modulated symbols and pilots perform a discrete Fourier transform (DFT) operation to produce frequency domain representation [2]. It then maps each of the DFT outputs to one of the orthogonal sub-carriers [12]. Finally, the IDFT module output is followed by a cyclic prefix (CP) insertion that completes the digital stage of the signal flow. Thus transmitted data propagating through the channel can be modeled as a circular convolution between the channel impulse response (CIR) and the transmitted data.

At the receiver, the reverse set of the operation is performed. After synchronization, CP samples are discarded and the remaining samples are processed by the DFT to retrieve the complex constellation symbols transmitted over the orthogonal sub-channels. After sub-carrier de-mapping, the received signal at pilot locations is extracted. In order to realize superior performance the receiver has to assess the impact of the channel. Consequently, a correct and efficient CE procedure is necessary to coherently demodulate the received data

III. ADAPTIVE RLS CE METHOD

An adaptive CE technique is a process that changes its parameters as it gain more information of its possibly changing environment. Among many iterative techniques that exist in the open literature, the well-liked classes of approaches which are achieve from the minimization of the MSE between the output of the adaptive filter and desired signal to perform CE as shown in Fig. 3.

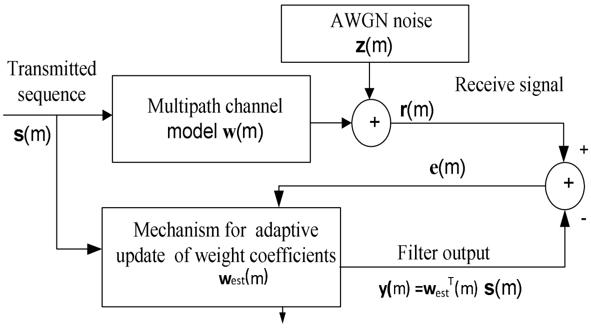

Fig. 3. Scheme for adaptive CE.

The signal **s**(m) is transmitted via a time-varying channel **w**(m), and corrupted by an additive noise estimated by using any kind of CE method. The main aim of most channel estimation algorithms is to minimize the mean squared error (MMSE) i.e., between the received signal and its estimate, while utilizing as little computational resources as possible in the estimation process. In the Fig 3, we have unknown multipath fading channel, that has to be estimated with an adaptive filter whose weight are updated based on some criterion so that coefficients of adaptive filter should be as close as possible to the unknown channel. The RLS CE requires all the past samples of the input and the desired output is available at each iteration. The objective function of a RLS CE algorithm is defined as an exponential weighted sum of errors squares:

$$c(m) = \sum_{m=1}^{n} \lambda^{n-m} \mathbf{e}^H(m)\mathbf{e}(m) + \delta\lambda^n \ \mathbf{w}^H(m)\mathbf{w}(m) \qquad (1)$$

where δ is a positive real number called regularization parameter, **e**(m) is the prior estimation error, and λ is the exponential forgetting factor with $0 < \lambda < 1$.
The prior estimation error is the difference between the desired response and estimation signal:

$$\mathbf{e}(m) = \mathbf{h}(m) - \mathbf{w}^H(m)\ \mathbf{s}(m) \qquad (2)$$

The objective function is minimized by taking the partial derivatives with respect to **w**(n) and setting the results equal to zero.

$$\frac{\delta c(m)}{\delta \mathbf{w}(m)} = 0 = -2 \sum_{m=1}^{n} \lambda^{n-m}\mathbf{s}(m)\mathbf{e}^H(m) + 2\delta\lambda^n\mathbf{w}(m)$$

$$= -2\sum_{m=1}^{n} \lambda^{n-m}\mathbf{s}(m)[\mathbf{h}(m) - \mathbf{w}^H(m)\mathbf{s}(m)]^H + 2\delta\lambda^n\mathbf{w}(m)$$

$$\mathbf{w}(m)[\sum_{m=1}^{n} \lambda^{n-m}\mathbf{s}(m)\mathbf{s}^H(m) + \delta\lambda^n\mathbf{I}] = \sum_{m=1}^{n} \lambda^{n-m}\mathbf{s}(m)\mathbf{h}^H(m)$$

$$\mathbf{R}_s(m)\mathbf{w}(m) = \mathbf{R}_{sh}(m)$$

$$\mathbf{w}(m) = \mathbf{R}_s^{-1}(m)\,\mathbf{R}_{sh}(m) \qquad (3)$$

where $\mathbf{R}_s(m)$ is the transmitted auto-correlation matrix

$$\mathbf{R}_s(m) = \sum_{m=1}^{n} \lambda^{n-m}\mathbf{s}(m)\mathbf{s}^H(m) + \delta\lambda^n\mathbf{I} = \lambda\mathbf{R}_s(m-1) + \mathbf{s}(m)\mathbf{s}^H(m)$$

and $\mathbf{R}_{sh}(m)$ is the cross correlation matrix i.e.,

$$\mathbf{R}_{sh}(m) = \sum_{m=1}^{n} \lambda^{n-m}\mathbf{s}(m)\mathbf{h}^H(m) = \lambda\mathbf{R}_{sh}(m-1) + \mathbf{s}(m)\mathbf{h}^H(m)\,.$$

According to the Woodbury identity , the above $\mathbf{R}_{sh}(m)$ can be written as

$$\mathbf{R}_{sh}^{-1}(m) = \lambda^{-1}\mathbf{R}_{sh}^{-1}(m-1) - \frac{\lambda^{-2}\mathbf{R}_{sh}^{-1}(m-1)\mathbf{s}(m)\mathbf{s}^H(m)\mathbf{R}_{sh}^{-1}(m-1)}{1+\lambda^{-1}\mathbf{s}^H(m)\mathbf{R}_{sh}^{-1}(m-1)\mathbf{s}(m)} \qquad (4)$$

For convenience of computing, let $\mathbf{D}(m) = \mathbf{R}_{sh}(m)$ and

$$\mathbf{K}(m) = \frac{\lambda^{-1}\mathbf{D}(m-1)\mathbf{s}(m)}{1+\lambda^{-1}\mathbf{s}^H(m)\mathbf{D}(m-1)\mathbf{s}(m)} \qquad (5)$$

The **K**(m) is referred as a gain matrix. We may rewrite (4) as:

$$\mathbf{D}(m) = \lambda^{-1}\mathbf{D}(m-1) - \lambda^{-1}\mathbf{K}(m)\mathbf{s}^H(m)\mathbf{D}(m-1) \qquad (6)$$

So simply (5) to $\mathbf{K}(m) = \mathbf{D}(m)\mathbf{s}(m) = \mathbf{R}_{sh}^{-1}(m)\mathbf{s}(m)$ (7)
Substituting (6), (7) into (3), we obtain the following RLS CE formula

$$\mathbf{w}(m) = \mathbf{w}(m-1) + \mathbf{K}(m)[\mathbf{h}(m) - \mathbf{w}^H(m-1)\mathbf{s}(m)]^H$$

$$= \mathbf{w}(m-1) + \mathbf{K}(m)\varepsilon^H(m), \qquad (8)$$

where $\varepsilon(m)$ is a prior estimation error as

$$\varepsilon(m) = \mathbf{h}(m) - \mathbf{w}^H(m-1)\mathbf{s}(m) \qquad (9)$$

Therefore equation (8) is the recursive RLS CE algorithm to update channel coefficient.

The complexity of CE algorithm is of vital importance especially for time varying wireless communication channels, where it has to be performed periodically or even continuously. Table I summarizes the computational complexity of the RLS CE technique, where L is the channel length, and real number indicates scalar operation. Here we assume that each iteration requires the evaluation of the inner product **D**(m)**h**(m) between two vectors of size L each. This calculation requires L multiplications and L-1 additions. Also assumed that the evaluation of the scalar addition or subtraction needs one real addition and multiplying the scalar by the vector requires L multiplications.

TABLE I
COMPLEXITY PER ITERATION

Operation	Complexity
Division	1
Multiplication	$L^2 + 5L+1$
Addition	$L^2 + 3L$

IV. EXPERIMENTAL RESULTS

In practice, the perfect channel coefficient is unavailable, so estimated channel coefficient must be used instead. The more correct estimated channel coefficient is, the better MSE performance of the CE will achieve. For simulation, we consider a wireless system operating with a bandwidth of 1.25MHz, with a total symbol period of 520µs, of which 10µs is a CP. The total channel bandwidth is divided into 128 subcarriers, implemented by 128-point IDFT. Sampling is performed with a 1.92MHz with BPSK modulation. Fig. 4 shows the MSE versus SNR for the RLS CE method with different Doppler frequencies 500Hz and 1.5kHz. One can observed that the RLS CE method with 500 Hz Doppler frequency has 3 dB better performances compared with 1.5k Hz Doppler frequency as desired. The similar behavior can be observed for BER performance in Fig. 5.

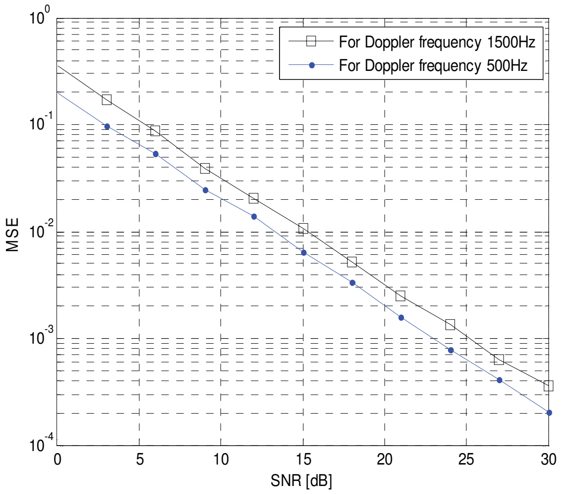

Fig. 4. MSE performance comparisons of the RLS CE method.

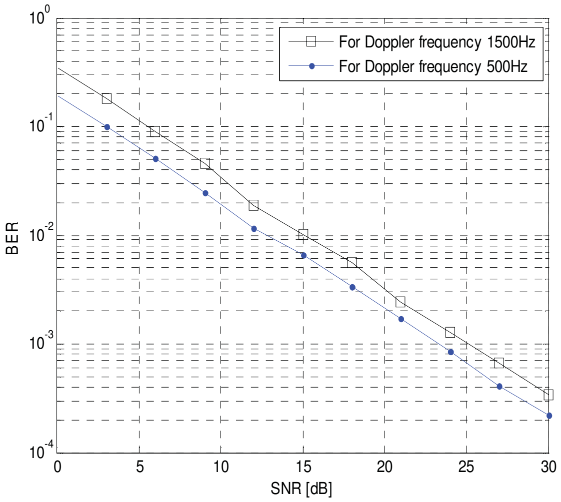

Fig. 5. BER performance comparisons of the RLS CE method.

V. CONCLUSION

In this paper, we explore the performance of RLS CE method for LTE SC-FDAM wireless communication systems with different Doppler frequencies. The complexities, MSE and BER performance of the RLS CE method, are analyzed and compared with the different Doppler frequencies. We can come to the conclusion that the RLS CE method with 500 Hz Doppler frequency has 3 dB superior performances compared with 1.5k Hz Doppler frequency.

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