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SVM based on LMMSE for high-speed coded OFDM channel with normal and extended cyclic prefix

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ABSTRACT

We propose in this article, a Linear Minimum Mean Squares Error-Support Vector Machine regression (LMMSE-SVR) method which is employed high-speed 3GPP Long Term Evolution (LTE) downlink coded channel estimation environment. LMMSE-SVR approach is applied to track and estimate the fast fluctuations caused by Doppler effect of a 3GPP realistic Extended Vehicular A model (EVA) channel. We integrate in this contribution both channel estimation at pilot symbols and interpolation at data symbols into the LMMSE-SVR process with and without turbo coding scheme. Bit Error Rate (BER) performance of our channel environment estimation proposal is validated via simulation of LTE downlink system for both coded and uncoded high-speed scenarios with normal and extended Cyclic Prefix (CP) modes.

1. Introduction

Due to Doppler effect in high mobility environments (e.g. up to 350 km/h in high speed trains), an efficient channel estimation and equalization is needed in order to assure the effectiveness of the transmitted information [1]. In high speed railways, the wireless communication channel relating the moving train and base station fluctuates very fast, which yields to the need of implementing a suitable algorithm to progress BER performance and therefore guarantee and assure the quality-of-service (QoS).

The Long Term Evolution (LTE) is a wireless communication standard which allows high data rate transmission under high speed mobility. In fact, LTE system, as a wideband high data rate wireless communication system, exploits the Orthogonal Frequency Division Multiplexing (OFDM) scheme due to its spectral efficiency and low complexity. To confront fast-fading multipath channel variations in high mobility railway communications, OFDM signals are appropriate at the receiver thanks to its robustness against rapid multipath fluctuations [2].

The 3GPP standard has not specified channel environment estimation techniques for LTE system, as a commercial system, from the received reference signals. In LTE downlink, reference signals are introduced at pre-defined positions in the OFDM symbols. Thus, using statements at these reference signal positions, the entire channel response can be estimated at the receiver side. Generally, the traditional frequency-domain channel estimation approaches lose their advantages when dealing with fast fading channel environments.

The use of support Vector Machine (SVM) as a machine learning approach in wireless communication presents many advantages compared to other learning approaches. First, it always converges to the same solution (the global optimum) for a given data set independently on the initial conditions. Additionally, it exhibits an aptitude to achieve a compromise between positive and negative errors using asymmetric soft margin. Moreover, SVM completely avoids the overfitting problem.

1.1. Related work

In the literature, reference signal-based channel environment estimation has been investigated, and the general suggested methods are grounded on Least Squares (LS) and Minimum Mean Squares Error (MMSE) [3]. The majority of these works take advantage of interpolation filters. Thus, channel estimates at the well-known reference signals are interpolated to furnish channel estimates at unknown data symbols.

The employment of linear MMSE (LMMSE) estimators for fast channel tracking have been suggested in numerous works. In papers [4] and [5], a conventional OFDM channel estimates based on LMMSE filter is introduced with the purpose of flatting the estimation error and interpolating the channel in time and frequency domains. Nevertheless, the channel is regarded as quasi-static within one OFDM symbol period. In [6], a LMMSE estimator using block-type pilot signals in time domain is proposed, which is

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not appropriate for high-mobility systems. Another interpolation method is suggested by [7] where the estimation of the channel impulse response is performed within each OFDM symbol, after that the variation is attained by exploiting linear fitting over the different estimations. The work [8] employs Expectation Maximization approach to estimate a semi-blind channel. In addition, [9] and [10] propose a time-domain training sequence to perform path delays estimation prior to each OFDM symbol whereas path delays are gotten by means of compressive sensing as in paper [11]. The work described in [12] exploits the OFDM block-type reference signals structure in the LTE uplink mode, which is specifically adapted to a flat fading channel with slow time variations. In this mode of transmission, one known OFDM symbol representing the training sequence, is estimated by MMSE technique in order to perform channel estimation in the followed OFDM data symbols in the LTE subframe by SVR interpolation approach. Nevertheless, in high mobility environments where channel is time-varying and frequency selective, block-type reference signals structure is not appreciated and thus comb-type pilot structure is suitable. In [13], authors exploit the comb-type pilot arrangement in frequency domain where estimation and interpolation are performed by LS and SVR techniques, respectively. However, and to the best of our knowledge, LMMSE-based SVR has not been proposed to estimate time-varying channel in OFDM systems as proposed in this paper.

1.2. Objectives and contributions

The main contribution of this paper is the design of a LMMSE-SVR algorithm adapted to OFDM comb-type pilot structure which accomplishes interpolation in frequency domain using Radial Basis Function (RBF) kernel with and without channel turbo coding scheme. This algorithm maps the indices of pilot positions (input vectors) from the input space (a finite-dimensional space) to a higher dimensional space provided with an inner product. Thus, SVR-based learning procedure is first performed for coded/uncoded channel estimation by LMMSE equalization technique at pilot positions and next interpolation is achieved using SVR approach by making use of these information with the aim of estimating the total channel frequency responses.

Principally, this work focuses on the major challenge of comb-type pilot-aided channel estimation and interpolation for a high-speed channel environment in 3GPP LTE downlink system with and without channel coding scheme. A combined channel estimation and interpolation technique is applied based on LMMSE method under SVR structure. Thus, the major contribution of this paper is (1) both coded and uncoded high-speed scenarios with normal and extended Cyclic Prefix (CP) modes are studied and established based on LMMSE-SVR channel estimation and interpolation approach according to 3GPP-LTE specifications; (2) a real scenario for Extended Vehicular A (EVA) model is simulated with 350 km/h mobile speed mixed with 64-QAM modulation scheme with turbo coding channel; (3) applicable to preamble and comb-type pilot pattern configurations.

1.3. Organization

The organization of this article is as follows. Section 2 provides an overview of the LTE downlink system model. In Section 3, we give the formulation of the proposed LMMSE-SVR estimation and interpolation approach. Section 4 presents simulation results and performance analysis. Finally, Section 5 concludes the work.

1.4. Notation

Notations: $(\cdot)^{-1}$, $(\cdot)^{\dagger}$ and $E(\cdot)$ refer to inverse, transpose conjugate and expectation, respectively.

2. System model

2.1. Transmitted signal

Let i symbolizes the OFDM symbol time index. First, a serial binary sequence $\boldsymbol{b}^T(i)$ is transformed into parallel sequences $\boldsymbol{b}(i)$, then, each data stream $\boldsymbol{b}(i)$ is mapped into a parallel symbol stream $\boldsymbol{X}^D(i)$ by means of digital Quadrature Amplitude Modulation (QAM). After that, reference symbols $\boldsymbol{X}^P(i)$ are inserted in the conforming locations as specified by the system. At this stage, the OFDM symbol $\boldsymbol{X}(i)$ characterizes data and pilot symbols in frequency domain. After application of Inverse Discrete Fourier Transformation (IDFT) on $\boldsymbol{X}(i)$, followed by parallel to serial conversion, the time-domain symbol $\boldsymbol{x}^T(i) = \boldsymbol{QX}(i)$ is obtained, with $\boldsymbol{Q}$ represents the $N \times N$ IDFT matrix. Next, a Guard Interval (GI) (or Cyclic Prefix (CP)) is inserted.

The OFDM symbol $\boldsymbol{X}(i)$ can be represented as the sum of $\boldsymbol{X}^D(i)$ and $\boldsymbol{X}^P(i)$, since the symbols $\boldsymbol{X}^D(i)$ and $\boldsymbol{X}^P(i)$ can be viewed as two orthogonal N-length OFDM symbols (by inserting zeros to pilot subcarriers for $\boldsymbol{X}^D(i)$, and to data subcarriers for $\boldsymbol{X}^P(i)$).

Similarly, the time-domain signal can be expressed as the sum of data $\boldsymbol{x}_d^T$ and pilot $\boldsymbol{x}_p^T$ signals as follows:

$$\boldsymbol{x}^T = \boldsymbol{x}_d^T + \boldsymbol{x}_p^T. \quad (1)$$

A channel coding is then considered in this chain by applying a channel turbo encoder with a base rate of 1/3, as specified in the LTE standard. Indeed, the turbo encoder output is composed of three streams. The first stream bits are generally mentioned as Systematic bits. The second and third streams bits which represent the outputs of the two constituent encoders are frequently denoted as Parity 1 and Parity 2 bit streams, respectively.

The trellis structure of the basic encoders and the turbo code internal interleaver specify the turbo encoder. In fact, the LTE interleaver permutes the input bits indices by means of a simple Quadratic Polynomial Permutation (QPP) technique. The relationship between the input index i and the output index $o(i)$ is expressed as follows:

$$o(i) = (c_1 \cdot i + c_2 \cdot i^2)\, mod(k) \quad (2)$$

where k stands for the input block size and c_1 and c_2 represent constants that depend on the k value. The basic encoder trellis structure is given by the two polynomials as follows:

$$P_0(z) = 1 + z^{-2} + z^{-3}$$
$$P_1(z) = 1 + z^{-1} + z^{-3}. \quad (3)$$

This explains a 1/3 turbo encoder with four states and with a trellis structure at each basic encoder characterized by both feed-forward and feedback connection polynomials.

2.2. Channel model

We take into account the following channel impulse response model of the wideband fast-fading multipath environment channel given by:

$$h(\tau, t) = \sum_{l=0}^{L-1} h_l(t)\delta(t - \tau_l), \quad (4)$$

with $h_l(t)$ stands for the impulse response that symbolizes the lth path complex channel gain, τ_l corresponds to the lth path random delay and L symbolizes the whole multipath replicas. The channel gains of diverse taps are assumed to be statistically independent, based on the supposition of a Wide Sense Stationary uncorrelated Scattering (WSSUS). Nevertheless, for a specific tap, the channel gains are correlated over time. Thus, the autocorrelation function