Review on Doppler Spread Estimation in MIMO Channel for OFDM

Rakesh Tiwari, Suresh Gawande

Department of Electronics and Communication, Bhabha Institute, Bhopal, India

Abstract - ***This paper review various Doppler spread estimation techniques available for MIMO channel OFDM. OFDM has been applied for various wireless communication systems in the last decade. Because of its tremendous success in digital video broadcasting (DVB) and wireless local area networks (WLANs), it is now considered for broadband wireless systems for both fixed and mobile applications such as wireless metropolitan area networks (WMANs), mobile broadband wireless access (MBWA) and proposed fourth generation (4G) cellular systems.***

Keywords - ***Doppler estimation, OFDM, spreading techniques.***

I. INTRODUCTION

In the current technological development the radio frequency front-end architectures used in radar and digital communication technology are becoming more and more similar. In both applications more and more functions that have traditionally been accomplished by hardware components are now being replaced by digital signal processing algorithms. Moreover, today's digital communication systems use frequencies in the microwave range for transmission, which are close to the frequency ranges traditionally used for radar applications. This technological advancement opens the possibility for the implementation of joint radar and communication systems that are able to support both applications on one single platform while utilizing a common transmit signal. A typical application area for such systems would be in the intelligent transportation networks, which require the ability of inter-vehicle communication as well as reliable environment sensing.

OFDM has been applied for various wireless communication systems in the last decade. Because of its tremendous success in digital video broadcasting (DVB) and wireless local area networks (WLANs), it is now considered for broadband wireless systems for both fixed and mobile applications such as wireless metropolitan area networks (WMANs), mobile broadband wireless access (MBWA) and proposed fourth generation (4G) cellular systems [1]. Those systems however, should be capable of working efficiently in wide range of operating conditions, such as large range of mobile subscriber station (MSS) speeds, different carrier frequencies in licensed and licensed-exempt bands, various delay spreads, asymmetric traffic loads in downlink and uplink and wide dynamic signal- to-noise ratio (SNR) ranges.

The aforementioned reasons motivated the use of adaptive algorithms in new generation wireless communication systems. Adaptation aims to optimize wireless mobile radio systems performance, enhance its capacity and utilize available resources in an efficient manner. However, adaptation requires a form of accurate parameter measurements. One key parameter in adaptation of mobile radio systems is the maximum Doppler spread. It provides information about the fading rate of the channel. Knowing Doppler spread in mobile communication systems can improve detection and help to optimize transmission at the physical layer as well as higher levels of the protocol stack [2]. Specifically, knowing Doppler spread can decrease unnecessary handoffs, adjust interleaving lengths to reduce reception delays, update rate of power control algorithms, etc. In addition, in OFDM systems, if the channel varies considerably within one OFDM symbol because of high MSS mobility, orthogonality between subcarriers is lost, leading to inter-carrier interference (ICI) [3]. Doppler information can help in selection of appropriate transmission profiles that are immune to ICI and hence the overall system performance will be improved.

II. BACKGROUND AND LITERATURE SURVEY

Various methods based on the auto-correlation function (ACF) have been used to estimate the Doppler spread f_d in single carrier systems [4]. In OFDM systems, the autocorrelation between the repeated parts of the symbol due to cyclic prefix (CP) is exploited in [5] to estimate the Doppler spread.

However, adaptive OFDM systems employ a form of variable CP size selection according to the delay spread of the channel. The part of the CP that is undisturbed by the multipath channel may be small especially when the environment causes large delay spread. This will degrade estimation greatly. Moreover, the results presented shows that the algorithm is biased at low and medium Doppler values, and gives good estimates at very high velocities which is less likely to occur. The scheme is also sensitive to SNR variations. In OFDM systems, channel estimates are often obtained in frequency domain. By obtaining the ACF of a certain subcarrier over several symbols, fd can also be estimated [6]. However, every subcarrier will have noise perturbation due to additive white Gaussian noise (AWGN) and ICI. In this paper, we overcome this bias by performing inverse fast Fourier transform (IFFT) to the channel estimates and then using the few obtained channel taps to get fd .

Some referred literature papers are discussed below:

A) Tevfik Y¨ucek, Ramy M. A. Tannious, and H¨useyin Arslan, "Doppler Spread Estimation for Wireless OFDM Systems", IEEE/Sarnoff Symposium on Advances in Wired and Wireless Communication, 2005

Author present a method for estimating the Doppler spread in mobile orthogonal frequency division multiplexing (OFDM) systems. The estimation is based on finding the autocorrelation function of time domain channel estimates over several OFDM symbols. In OFDM systems channel estimation is popularly performed in frequency domain. Channel frequency response estimates are affected by noise and inter-carrier interference (ICI). As a result, Doppler estimates based on frequency domain channel estimates will be affected significantly. Author show that use of channel estimates in time domain can greatly improve the performance of Doppler estimates. The channel impulse response (CIR) can be obtained by taking IDFT of the channel frequency response (CFR). Consequently the proposed method will reduce processing time and memory usage. Computer simulations support our claim for a broad range of Doppler spread and signal-to-noise ratio (SNR) values in Rayleigh fading channels [7].

B) Yoke Leen Sit, Christian Sturm, and Thomas Zwick, "Doppler Estimation in an OFDM Joint Radar and Communication System", Proceedings of the 6th German Microwave Conference, IEEE 2011

This paper propose a processing algorithm that allows for estimating the velocity of multiple reflecting objects with standard OFDM communication signals is discussed. This algorithm does not require any specific coding of the transmit data. The technique can be used in combination with a range estimation algorithm in order to implement active radar sensing functions into a communication system for vehicular applications. This scheme operates regardless of the transmitted signal information and coding by processing the symbols that compose the OFDM symbols directly instead of processing the baseband signals. Therefore the algorithm can be applied in combination with the transmission of arbitrary user data and is able to resolve multiple reflecting objects with a high dynamic range and low sidelobe levels [8].

C) **J.Tao, J. Wu, and C. Xiao, "Doppler Spread Estimation for Broadband Wireless OFDM Systems Over Rician Fading Channels", Int J Wireless Inf Networks (2009)**

In this paper, Author present a new Doppler spread estimation algorithm for broadband wireless orthogonal frequency division multiplexing (OFDM) systems with fast time-varying and frequency-selective Rayleigh or Rician fading channels. The new algorithm is developed by analyzing the statistical properties of the power of the received OFDM signal in the time domain, thus it is not affected by the influence of frequency-domain inter-carrier interference (ICI) introduced by channel variation within one OFDM symbol. The operation of the algorithm doesn't require the knowledge of fading channel coefficients, transmitted data, or signal-to-noise ratio (SNR) at the receiver. It is robust against additive noise, and can provide accurate Doppler spread estimation with SNR as low as 0 dB. Moreover, unlike existing algorithms, the proposed algorithm takes into account the inter-tap correlation of the discrete-time channel representation, as is the case in practical systems. Simulation results demonstrate that this new algorithm can accurately estimate a wide range of Doppler spread with low estimation latency and high computational efficiency [9].

D) A. Doukas, G. Kalivas, "Doppler Spread Estimation in Frequency Selective Rayleigh Channels for OFDM Systems ", IEEE 2011

In this paper, Author present a method for estimating the Doppler spread (DS) in Wireless Local Area Networks (WLAN) using Orthogonal Frequency Division Multiplexing (OFDM). DS gives a measure of the fading rate of the wireless channel, which can be used to adjust the channel estimation rate and create specifically designed channels estimators to combat Inter-Carrier Interference (ICI) induced due to loss of orthogonality that DS imposes on OFDM systems. The estimation is based on the autocorrelation function of time domain channel estimates over two OFDM symbols and since that most of the receiver algorithms require knowledge if the receiver moves or not we divide the operation region into two modes: still mode(S-mode) and moving mode (M-mode). The estimation accuracy, examined in environments with different PDPs, including channel sparsity, using several constellation schemes is quite accurate from low SNR values of 5 dB [10].

E) Y. Choi, O..C.Ozdural, H. Liu, and S.Alamouti, "A Maximum Likelihood Doppler Frequency Estimator for OFDM Systems", IEEE International Conference on Communications, 2006. ICC '06.

This paper derives a maximum likelihood Doppler frequency estimator for orthogonal frequency division multiplexing (OFDM) systems in time-varying multipath channels.

The proposed scheme is a frequency-domain approach that utilizes pilot subcarriers, which are commonly implemented in most practical systems. Time-varying fading causes intercarrier interference (ICI) in OFDM systems. Thus, in the proposed estimator, the effect of ICI is taken into consideration with a proper model for accurate results. The estimator can be implemented using a finite impulse response (FIR) filter bank whose coefficients can be pre-calculated and stored in order to lower the computational complexity. Author evaluate various methods to improve the estimation accuracy and analyze their complexity-performance tradeoffs. They also derive the Cram´er-Rao bound and provide simulation results to quantify the performance of the proposed algorithm [11].

III. METHODOLOGY

In OFDM encoding of digital data is done on multiple carrier frequencies. OFDM has developed into a popular scheme for wideband digital communication, whether wireless or over copper wires, used in applications such as digital television and audio broadcasting, DSL broadband internet access, wireless networks, and 4G mobile communications. OFDM is essentially identical to coded OFDM (COFDM) and discrete multi-tone modulation (DMT).

OFDM a large number of closely spaced orthogonal sub-carrier signals are used to carry data in OFDM. The data is divided into several parallel data streams or channels, one for each sub-carrier. Each sub-carrier is modulated with a conventional modulation scheme (such as quadrature amplitude modulation or phase-shift keying or QPSK) at a low symbol rate, maintaining total data rates similar to conventional *single-carrier* modulation schemes in the same bandwidth.

The primary advantage of OFDM over single-carrier schemes is its ability to cope with severe channel conditions (for example, attenuation of high frequencies in a long copper wire, narrowband interference and frequency selective fading due to multipath) without complex equalization filters. Channel equalization is simplified because OFDM may be viewed as using many slowly modulated narrowband signals rather than one rapidly modulated wideband signal. The low symbol rate makes the use of a guard interval between symbols affordable, making it possible to eliminate intersymbol interference (ISI) and utilize echoes and time-spreading (that shows up as ghosting on analogue TV) to achieve a diversity gain, i.e. a signal-to-noise ratio improvement. This mechanism also facilitates the design of single frequency networks (SFNs), where several adjacent transmitters send the same signal simultaneously at the same frequency, as the signals from multiple distant transmitters may be combined constructively, rather than interfering as would typically occur in a traditional single-carrier system.

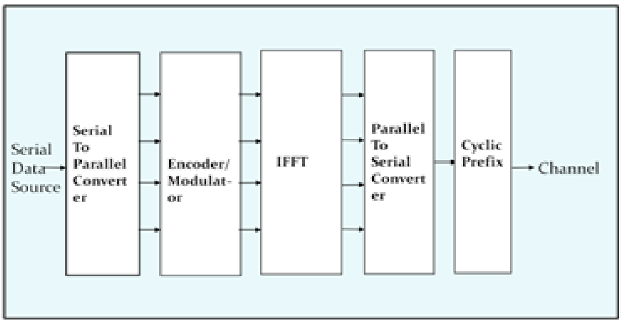


Fig 1.1 OFDM Transmitter

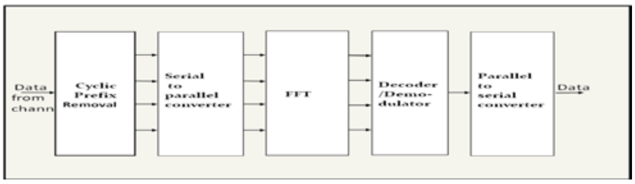


Fig 1.2. OFDM Receiver

Communication channels introduce noise, fading, interference, and other distortions into the signals that they transmit. Simulating a communication system involves modeling a channel based on mathematical descriptions of the channel. Different transmission media have different properties and are modeled differently. There are three kind of channels used in communication:

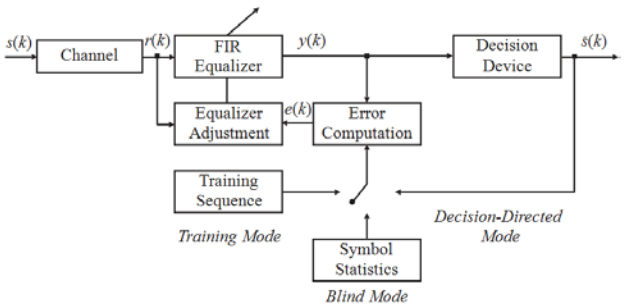
1. Additive white Gaussian noise (AWGN) channel
2. Multiple-Input Multiple-Output (MIMO) channel
3. Fading channel

Equalizers:

Time-dispersive channels can cause intersymbol interference (ISI). For example, in a multipath scattering environment, the receiver sees delayed versions of a symbol transmission, which can interfere with other symbol transmissions. An equalizer attempts to mitigate ISI and thus improve the receiver's performance.

Adaptive Equalization

Adaptive equalizers compensate for signal distortion attributed to intersymbol interference (ISI), which is caused by multipath within time-dispersive channels. Typically employed in high-speed communication systems, which do not use differential modulation schemes or frequency division multiplexing. The equalizer is the most expensive component of a data demodulator and can consume over 80% of the total computations needed to demodulate a given signal.



Adaptive Equalization

Blind Equalization

Blind equalization is a digital signal processing technique in which the transmitted signal is inferred (equalized) from the received signal, while making use only of the transmitted signal statistics. Hence, the use of the word *blind* in the name.

Blind equalization is essentially blind deconvolution applied to digital communications. Nonetheless, the emphasis in blind equalization is on online estimation of the equalizer filter, which is theinverse of the channel impulse response, rather than the estimation of the channel impulse response itself. This is due to blind deconvolution common mode of usage in digital communications systems, as a mean to extract the continuously transmitted signal from the received signal, with the channel impulse response being of secondary intrinsic importance.

The estimated equalizer is then convolved with the received signal to yield an estimation of the transmitted signal.

MMSE Equalization

A Minimum Mean Square Error (MMSE) estimator describes the approach which minimizes the mean square error (MSE), which is a common measure of estimator quality. The main feature of MMSE equalizer, is that it does not usually eliminate ISI completely but , minimizes the total power of the noise and ISI components in the output [25] (Sathish Kumar, et al., 2011; Jinag et al., 2011).

Let x be an unknown random variable, and let y be a known random variable. An estimator

$x_i(y)$ is any function of the measurement y, and its mean square error is given by

$$MSE = E\{[X_i^2 - X^2]\}$$

Where the expectation is taken over both x and y.

The MMSE estimator is then defined as the estimator achieving minimal MSE. In many cases, it is not possible to determine a closed form for the MMSE estimator. In these cases, one possibility is to seek the technique minimizing the MSE within a particular class, such as the class of linear estimators [26] (Cho et al., 2002). The linear MMSE estimator is the estimator achieving minimum Mean square error among all estimators of the form AY + b. If the measurement Y is a random vector, A is a matrix and b is a vector.

Let us now try to understand the mathematics for extracting the two symbols which interfered with each other

$$y_1 = h_{1,1}x_1 + h_{1,2}x_2 + n_1 = [h_{1,1}\ h_{1,2}]\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_1$$

The receive Signal on the second receiving antenna is

$$y_2 = h_{2,1}x_1 + h_{2,2}x_2 + n_2 = [h_{2,1}\ h_{2,2}]\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_2$$

Where

y_1, y_2 : are the received symbol on the first and second antenna respectively,

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$h_{1,1}$ is the channel from 1st transmit antenna to 1st receive antenna,

$h_{1,2}$ is the channel from 2nd transmit antenna to 1st receive antenna,

$h_{2,1}$ is the channel from 1st transmit antenna to 2nd receive antenna,

$h_{2,2}$ is the channel from 2nd transmit antenna to 2nd receive antenna,

x_1, x_2 are the transmitted symbols and n1, n2 are the noise on 1st and 2nd receive antennas.

IV. CONCLUSIONS

Literature has been studied thoroughly, Doppler spread estimation for mobile OFDM systems in Rayleigh fading channels is studied. Doppler spread is estimated using the time domain channel estimates instead of frequency domain channel response. A theoretical parameterization study has also been discussed in which suitable values have been derived for the operation of both the radar and the communication function for the typical application area of car-to-car communication.

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