CHAPTER

1

# INTRODUCTION

## 1.1 Background

Fourth Generation wireless and mobile systems characterized by broadband wireless systems are currently the focus of research and development among the researchers everywhere. The broadband wireless systems favor the use of orthogonal frequency division multiplexing (OFDM) modulation that allows high data-rate communication. A major advantage of OFDM systems is its ability to divide the input high rate data stream into many low-rate streams that are transmitted in parallel. Doing so increases the symbol duration and reduces the intersymbol interference over frequency-selective fading channels [Van Nee, 2000]. This and other features of equivalent importance have motivated the adoption of OFDM as a standard for several applications such as digital video broadcasting (DVB) and broadband indoor wireless local area networks, broadband wireless metropolitan area networks and many others.

In order to exploit all these advantages and maximize the performance of OFDM systems; channel state information (CSI) plays a very important role. Signal-to-noise ratio (SNR) is a quantity that gives a comprehensive measure of CSI for each frame. An on-line SNR estimator thus provides the knowledge to decide whether a transition to higher bit rates would be favorable or not.

Signal-to-noise ratio (SNR) is broadly defined as the ratio of desired signal power to the noise power. Noise variance and hence signal to noise ratio (SNR) estimates of the received signal are very important for the channel quality control in communication systems. The search for a good SNR estimation technique is also motivated by the fact that various algorithms require knowledge of the SNR for optimal performance. For instance, in OFDM systems, SNR estimation is used for power control, adaptive coding and modulation, turbo decoding, diversity combing, etc.

One of the purposes of acquiring SNR estimates in a wireless communication channel is to use this information to evaluate the link reliability. In worldwide inter operability for microwave access (WiMAX) systems, the knowledge of the SNR is used for throughput optimization by selecting one out of seven burst where the selected profile changes according to the measured SNR. As in adaptive modulation and coding, a higher modulation and coding rate is used in high SNR conditions, while a lower and noise robust modulation formats is used in low SNR conditions. Each burst profile has some threshold values of SNR. These threshold values of SNR are used to adapt different burst profiles on the basis of channel state information.

Several SNR estimation algorithms have been suggested in the past for single carrier systems presuming ISI free reception of the system. SNR estimation for multicarrier systems (OFDM) were presented first in nineties. There is not that much work found for SNR estimation in OFDM systems. SNR estimation algorithm for multicarrier systems suggested in the past by [Shousheng et.al, 1998], [Reddy, S. et al, 2003], [ Bournard, S, et al,2003], [ Taesang, Y. et al, 2004],[ Xiaodong X. et al ,2005], [Yucek et al, 2005], [Doukas et al, 2006] and have been successfully implemented previously in OFDM systems by making use of the pilot symbols that are inserted in the OFDM symbol. Extracting pilots and using them for SNR estimation is computationally complex. The need is of an SNR estimator of low computational complexity so as to keep hardware costs minimum while keeping estimation error minimum. This is the motivating factor for the pursuit of an SNR estimator that does not require the manipulation of pilot symbols. SNR estimator presented in the past performed SNR at the back-end of the receiver. So, there is enough interest in estimating SNR at the front-end of the receiver which has added advantages of fast and efficient inline diversity combining, adaptive modulation and coding. For systems that use preamble for synchronization and channel estimation, this is feasible and designed in this thesis.

## 1.2 Types of SNR Estimators

All the estimation algorithms mentioned above can be divided into two classes. One class is data-aided estimator (DA-SNR estimator) for which known (training sequence or pilot) data is transmitted and the SNR estimator at the receiver uses the known data to estimate the SNR. The other class is the non-data-aided estimator. For this class of estimator, no known data is transmitted, and therefore the SNR estimator at the receiver has to blindly estimate the SNR value.

Various specific DA-SNR estimators are discussed in more detail in later sections, but there are two general types classified according to whether the data is used to aid the SNR estimation is known or estimated. An estimator that uses an exact, known copy of the transmitted message sequence will be referred to as a TxDA estimator.

A DA-SNR estimator that uses an estimate of the transmitted message sequence provided by receiver decisions will be referred to as an RxDA estimator. As a further classification, any SNR estimator that can generate SNR estimates from the unknown, information-bearing portion of the received signal is often referred to as an in-service estimator. RxDA-SNR estimators are of the in-service type.

In TxDA-SNR estimation, the fidelity of the message sequence used for SNR estimation is assured by making an exact copy of the transmitted message sequence available to the receiver. As an example, short blocks of known data may be inserted periodically into the information-bearing sequence. DA equalization techniques use so-called training sequences for a similar purpose [J.G.Proakis, 1989].

A throughput penalty is incurred since some channel capacity must be devoted to the transmission of non information- bearing data (training sequences are not considered to carry information because the data is already known to the receiver). However, in systems which already employ training sequences for equalization or synchronization, there would be no additional throughput penalty since those same known sequences could be used to maximize the performance of a DA-SNR estimator.

Note that since TxDA-SNR estimates can only be generated when known data is available at the receiver, the use of a TxDA-SNR estimator may not be appropriate in some situations where a continuous stream of SNR estimates is required.

Since receiver decisions are subject to error, the performance of RxDA-SNR estimation is inferior to that of TxDA-SNR estimation at low SNR where decision errors are more likely. An advantage of RxDA-SNR estimation is that the SNR information is extracted directly from the information-bearing signal with no loss of throughput due to resource overhead. Since RxDA-SNR estimates may be generated whether the transmitted symbols are known or unknown, RxDA-SNR estimators may be used in applications that require a continuous stream of SNR estimates

## 1.3 SNR Estimation Problem Statement

In this work, an estimator of type Rx-DA-SNR is proposed. It makes use of the synchronization preamble. Most synchronization schemes of today are based on Schmidl & Cox technique [Schmidl et al, 1997], which uses alternate loading of subcarriers with known PN sequence. Such alternate loading leads to two identical halves property in the preamble. Since the preamble used for the proposed method is the timing synchronization preamble in OFDM system so there is no additional throughput penalty.

According to best knowledge of the author, there is no work done at front-end of the receiver for OFDM systems. Herein, a front-end estimation of noise power and SNR based on one OFDM preamble symbol used for synchronization is proposed.

There are two main tasks that need to be addressed in preamble based SNR estimation. Firstly, selection of training or preamble signal that will sound out the channel effectively and effeciently. In an OFDM system, this means that the preamble signal should have equal power in all subcarriers and peak to average power ratio (PAPR) of the preamble signal should be as small as possible. Given the same system power, the preamble with a lower PAPR can be power boosted more. This results in a better estimation of signal to noise ratio (SNR).

After selecting an efficient preamble, the other major task is the development of SNR estimation technique that can estimate the SNR at front-end of the receiver with only one OFDM preamble symbol.

## 1.4 Objectives of the Research

There are three main objectives of the research work. These are outlined as follows:

- A complete end-to-end IEEE802.16d compliant OFDM-FBWA system will be developed in Matlab® for the purpose of evaluating the performance of proposed SNR estimation technique in both frequency non-dispersive and dispersive channels with real additive white Gaussian noise (AWGN) and also colored noise.

- Front-end SNR estimation technique based on one OFDM preamble will be developed that has desirable properties of minimal estimation error in mean squared sense and will provide accurate estimates of SNR in term of only one training symbol. The results will be compared with other works reported in the literature.

- The technique will also be extended to obtaining noise power estimates of colored noise using wavelet-packet based filter bank analysis of the noise.

## 1.5 Contribution of This Thesis

- A novel SNR estimation technique for OFDM systems is reported. It makes use of timing synchronization preamble used in many OFDM systems. There is no extra overhead as the preamble used for SNR estimation is already employed in OFDM systems. It estimates the SNR by auto correlating the received preamble. Complexity of proposed estimator to find SNR estimates is much lower than other SNR estimators because it is based on only one OFDM preamble.

- The proposed technique, when employed up-front in the presence of cyclic prefix (CP), gives better estimates of SNR over AWGN channel and multipath channels (Rayleigh & Rician). The technique is also extended to estimates the SNR over colored noise using wavelet packet.

- The proposed technique, when employed after CP removal, can also estimate SNR over colored noise using wavelet packet analysis.

- Wavelet packet based FFT implementation is also reported in this thesis in appendix B where SNR estimation is performed inside FFT for both AWGN and colored noise.

## 1.6 Organization of Thesis

This thesis is structured as follows. Chapter 2 presents the background of OFDM systems and its advantages when used in wireless channels. It is followed by the literature review of SNR estimation for different systems and later by literature review about SNR estimation for OFDM systems, - the topic of this thesis. Formulation of SNR estimation algorithms used later for comparing them with the proposed technique is also presented. This chapters ends with the applications which may be benefited from the knowledge of SNR.

Chapter 3 presents the formulation of proposed front-end SNR estimation. The proposed technique makes use of one OFDM synchronization preamble - the preamble which has two identical halves property. Benefit of using this preamble is discussed in selection of preamble section. Proposed technique is designed for additive white Gaussian noise (AWGN) channel and multipath channels and also extended to obtain the noise power estimates of colored noise using wavelet-packet based filter bank analysis of the noise. The proposed technique is deployed at the front-end of the receiver unlike all other SNR estimators for OFDM systems discussed in chapter 2. In the last section methodologies of proposed estimator as well as the estimators used later for comparison are presented. It lists the selected parameters for proposed as well as other SNR estimators that have been used for comparison in our simulations.

In chapter 4, results of proposed work is presented and discussed. The results are compared with previously published SNR estimators for both white noise and colored noise scenario respectively. The results shows that the proposed estimator with one OFDM preamble perform better than other SNR estimators which makes use of many OFDM symbols to obtain the accurate estimates of SNR. The purposed method is also checked with the WiMAX systems (IEEE802.16d) using SUI channels and also with IEEE802.11g systems using indoor channel models.

Chapter 5 presents the conclusions and suggests the future works.

Appendix A discusses Wavelet Packets used in this technique.

Appendix B presents the wavelet packet based FFT and its use in SNR estimation for both AWGN and colored noise.