Chapter 3

Wimax Overview

Wimax Phy. Layer is based on orthogonal frequency division multiplexing (OFDM). OFDM is the transmission scheme of choice to enable high-speed data, video and multimedia communications and is used by a variety of commercial broadband systems, including DSL, Wi-Fi, Digital Video Broadcast-Hand held (DVB-H) and WiMAX. Also, OFDM is an efficient scheme for high data rate transmission in a non-line-of-sight (NLOS) or multipath radio environment.

3.1 Wimax: An Example of MIMO-OFDM System

3.1.1 Transmitter

Block Diagram in Fig.(3.1) shows various functional stages of a Wimax Phy. Layer. As a specific case DownLink Transceiver of 802.16m is considered here. It consists of a Channel Encoder, QAM Mapper, MIMO Mapper, Resource allocation, Carrier mapping by IFFT and (Cyclic Prefix) CP addition block (to prevent ISI). A brief description of each block is given below.

Channel Coding

Channel coding stage consists of the following steps: (1) data randomization, (2) channel coding, (3) rate matching, (4) HARQ, if used and (5) interleaving.

Data randomization is performed in the uplink and the downlink, using the output of a maximum length shift-register sequence that is initialized at the beginning of every FEC block. The purpose of the randomization stage is to provide layer 1 encryption and to prevent a rogue receiver from decoding the data. Channel coding is performed on each FEC block which adds redundancy in the code. By means of rate matching, any arbitrary code rate can be achieved from a fixed-rate mother
code. Any code rate \( r \) can be obtained from the initial 1/3 code via a process of bit puncturing for \( r \geq (1/3) \)) or repetition \( r \leq (1/3) \). Interleaving helps to provide maximum decorrelation between two Turbo encoded data sequences. This helps during channel fades as both sequences cannot be similarly affected. Generally, Turbo codes are used for channel encoder due to their better convergence, greater minimum distances between generated codewords, less sensitivity to puncturing patterns and robustness of the decoder\[59]\[56].

**QAM-Mapper**

The sequence of binary bits is converted to a sequence of complex valued symbols. The constellations are QPSK and 16 QAM, 64 QAM constellation. Each modulation constellation is scaled by a number \( c \), such that the average transmitted power is unity. The value of \( c \) is \( \sqrt{1/2} \), \( \sqrt{1/10} \) and \( \sqrt{1/42} \) for the QPSK, 16 QAM, and 64 QAM modulations, respectively.

**MIMO Mapper**

There are various MIMO open loop and close loop modes with transmit and receive diversity as explained earlier. Here, the work consider only SM case in particular with SU-MIMO (Single
User-MIMO) case to achieve high throughput.

MIMO Mapper is made of MIMO encoder and MIMO precoder. MIMO encoder maps input MIMO layers to MIMO streams. MIMO layer is an information path fed to the MIMO encoder as an input. For example, in SFBC encoding, the input data $s = [s_1, s_2, s_3,...]$ to MIMO encoder is divided in pairs of consecutive $2 \times 1$ sample pairs (MIMO layer). The first pair is

$$\begin{pmatrix} s_1 \\ s_2 \end{pmatrix}$$

MIMO encoder encodes

$$\begin{pmatrix} s_1 & -s_2^* \\ s_1^* & s_2 \end{pmatrix}$$

Since here SM case with $4 \times 4$ antenna is considered, MIMO stream mapping (Vertical encoding) is

$$\begin{pmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{pmatrix}$$

MIMO precoder uses a set of codebooks to map MIMO stream to antenna. The output of the MIMO encoder is multiplied by a precoder weight matrix W. The Matrix from the codebook is chosen according to some fixed statistics in open loop and channel feedback knowledge in closed loop. Precoder is much more useful for directional beamforming when multiuser MIMO is used. It helps to nullify or minimize interference for a selected user due to other users’ data transmission.

**Resource Mapper**

According to channel conditions, the data is allocated to available resource subchannels. A subchannel is a group of subcarriers (orthogonal frequencies in this case). Under good channel conditions, large band of adjacent subcarriers are assigned. However, under worst conditions, adjacent data is assigned to permuted subcarriers, so that the resultant signal doesn’t experience a continuous deep fade. Pilots are added in the resultant block signal while fulfilling the delay spread and coherence time spacing in time-frequency subframe grid to carry out channel estimation at the receiver.

**IFFT**

It assigns orthogonal frequencies (OFDM as explained earlier) to MIMO data streams from MIMO Mapper block.
Wireless Channels

Data is transmitted by multiple antennas and propagates through multipath fading channel with additive noise as explained earlier.

3.1.2 Receiver

Channel Estimation

This block is responsible for tracking the channel multipath effect and time variation and is described in detail in a later chapter. The first block in the receiver is the channel estimator. The need for channel estimation has been explained earlier. Previous work for SISO/MIMO channel estimation, Block/Comb pilot interpolation based Slow-Fast fading channel estimation, Wimax channel estimation requirements and proposed joint Coarse-Fine channel estimation methods is detailed in other chapters.

MIMO Hard/Soft Detection

Once the channel is estimated, then MIMO data streams are detected using various MIMO linear and OSIC detectors. Soft QR-OSIC based detectors are optimal in terms of performance and complexity, but they suffer from EVS (Empty Vector Set) problem. The appropriate solution while achieving soft ML capacity is described in detail in a later chapter.

CTC Decoder

The decoder is iterative Turbo decoder and uses Max log Map, BCJR algorithm[3][56]. The decoder uses 3-4 internal iterations and exchanges soft information between two internal decoders back and forth to achieve extrinsic gain. Usefulness of extrinsic gain in achieving soft ML capacity is explained in a later chapter. The other blocks like MIMO demapper, QAM demapper are dual of transmitter blocks.

3.2 Wimax Frame Format

As shown in Table 775 of [23], various OFDMA parameters are considered for different channel bandwidths. Here the work concentrate on one particular case with parameters as shown in Fig.(3.2).
The advanced air interface basic frame structure is illustrated in Fig (3.3). Each 20 ms superframe is divided into four equally-sized 5 ms radio frames. When using the same OFDMA parameters with the channel bandwidth of 20 MHz, each 5 ms radio frame further consists of eight AAI subframes for G = 1/8. An AAI subframe shall be assigned for either DL (Down Link) or UL (Up Link) transmission. Two types of AAI subframes are considered:

1) The type-1 AAI subframe which consists of six OFDMA symbols,
2) The type-3 AAI subframe which consists of five OFDMA symbols.

The basic frame structure is TDD duplexing. The number of switching points in each radio frame is two, where a switching point is defined as a change of directionality, i.e., from DL to UL or from UL to DL.
3.2.1 TDD Frame Structure

In a TDD frame with DL to UL ratio of D:U (Down Link to Up Link), the first contiguous D AAI subframes and the remaining U AAI subframes are assigned for DL and UL respectively, where $D + U = 8$ for 20 MHz channel bandwidths. TTG (Transmit Transition Gap) and RTG (Receive Transition Gap) are 105.714 $\mu$s and 60 $\mu$s, respectively.

Downlink Physical Structure [23]

Each down link AAI subframe is divided into 4 or fewer frequency partitions. Each partition consists of a set of physical resource units across the total number of OFDMA symbols available in the AAI subframe. Each frequency partition can include contiguous (localized) and/or non-contiguous (distributed) physical resource units.

Physical and Logical Resource Unit

A PRU (Physical Resource Unit) is the basic physical unit for resource allocation that comprises Nsc consecutive subcarriers by Nsym consecutive OFDMA symbols. Nsc is 18 subcarriers and Nsym is 6 and 5 OFDMA symbols for type-1 and type-3 AAI subframes respectively. A LRU (Logical Resource Unit) is the basic logical unit for distributed and localized resource allocations. An LRU is Nsc·Nsym subcarriers for type-1 AAI subframes, type-3 AAI subframes. The effective number of subcarriers in an LRU depends on the number of allocated pilots. Fig. (3.4) describes various resorce units.

Distributed Logical Resource Unit

The DLRU (Distributed Logical Resource Unit) consists of a group of subcarriers that are spread across the distributed resource allocations within a frequency partition. The size of the DLRU equals the size of PRU, i.e., Nsc subcarriers by Nsym OFDMA symbols. The minimum unit for forming the DLRU is equal to a pair of subcarriers called a tone-pair. The DLRUs are obtained by subcarrier permutation of the DRUs (Distributed Resource Units).

Contiguous Logical Resource Unit

The localized logical resource unit, also known as CLRU (Contiguous Logical Resource Unit) contains a group of subcarriers that are contiguous across the localized resource allocations. The size of the CLRU equals the size of the PRU, i.e., Nsc subcarriers by Nsym OFDMA symbols. The
CLRUs are obtained from direct mapping of Contiguous Resource Units (CRUs). Two types of CLRUs, Subband LRU (SLRU) and Miniband LRU (NLRU), are supported respectively. Here the work concentrate on Subband CRUs only.

**Subband vs. Miniband**

The PRUs are first subdivided into subbands and minibands. A subband comprises of $N_1$ adjacent PRUs and a miniband comprises of $N_2$ adjacent PRUs, where $N_1 = 4$ and $N_2 = 1$. Subbands are suitable for frequency selective allocations as they provide a contiguous allocation of PRUs in frequency. Minibands are suitable for frequency diverse allocation and are permuted in frequency.

**Pilot Structure**

The transmission of pilot subcarriers in the down link is necessary for enabling channel estimation, measurement of channel quality indicators such as the SINR, frequency offset estimation, etc. The pilot patterns on stream 0 - stream 3 for four pilot streams are shown in Fig. (3.5).

**Advanced Preamble**

There are two types of Advanced Preamble (A-Preamble): Primary Advanced Preamble (PA-Preamble) and Secondary Advanced Preamble (SA-Preamble). One PA-Preamble symbol and three SA-Preamble symbols exist within the superframe. The location of the A-Preamble symbol is specified as the first symbol of the frame. SA-Preamble for 2048 FFT, 4 antenna case is shown in Fig. (3.6), which shows that generated preamble sequence for four antennas are orthogonal and do not contribute interference to each other. Here, the work utilizes SA-Preamble to estimate channel
As seen in the frame format, preamble is followed by subframe zero. It consists of SFH (Super Frame Header), A-MAP and data burst. SFH contains control data information like, frequency offset, OFDM symbol number for data burst start and end, number of users, number of CRUs/DRUs allocated etc. Subframe 1 and 2 follow subframe 0, which consists of data bursts allocated in different frequency partitions. MIMO midamble then follows which is used for Channel Quality Information (CQI) during MIMO close loop configuration. CQI estimated at mobile station using MIMO midamble is then fed back for codebook selection when used in MU-MIMO environment. Subframe 4 and 5 contain data burst which is followed by TTG and UL data.