The aims of this appendix is to describe the architecture and packet format used at the WiMAX PHY and MAC layers. These descriptions may be useful in Section 8.3, page 232, which introduces some robust burst segmentation techniques applied to WiMAX.

**Z.1 OVERVIEW OF THE WiMAX STANDARD**

WiMAX, also known as IEEE 802.16 (IEEE, 2004), is intended for wireless metropolitan area networks (MANs) and last-mile wireless broadband services (backhaul). In a MAN, WiMAX can provide broadband wireless access (BWA) over a radius of up to 30 miles (50 km) for fixed stations and 3–10 miles (5–15 km) for mobile stations. In contrast, the WiFi/802.11 (IEEE, 1999) wireless local area network standard is limited in most cases to only 100–300 feet (30–100 m).

WiMAX provides a robust, reliable, and cost-effective means to deliver broadband services in metropolitan and rural areas. The most outstanding advantage of BWA is its low cost for installation and maintenance compared with traditional wire or fiber network access, especially for those areas that are too remote or difficult to reach. Networks could be created in a short time by deploying a small number of base stations (BS) on buildings or poles to create high-capacity wireless access systems. Whether WiMAX or 3G LTE (Dahlman et al., 2007) will be deployed in the future is an open question, which is not of importance here, our intent is to show that the main redundancy properties still hold in this case.

With 802.16e (IEEE, 2006), mobility based on handover is introduced in WiMAX. Handover operation (sometimes also known as *handoff*) is the fact...
that a mobile user goes from one cell to another without interrupting the ongoing session (whether a phone call, data session, or other). The handover can be due to mobile subscriber moves, radio channel condition changes, or cell capacity considerations.

The IEEE 802.16 standard defines two possible network topologies: mesh and point-to-multipoint (PMP). In the PMP mode, traffic may take place only between a BS and its subscriber stations (SSs), while in the mesh mode the traffic can be routed through other SSs up to the BS and can even operate only between SSs. The 802.16-2004 (IEEE, 2004) standard consists of a definition of multiple PHY layers and a single MAC layer. The PHY and MAC definitions are quite closely coupled in 802.16, and, consequently, it is difficult to make a clear separation between them in the model.

Z.1.1 PHY Layer in WiMAX

The following five physical interfaces are defined in the 802.16 standard.

2. WirelessMAN-SCa (using as SC in the 2–11 GHz band)
3. WirelessMAN-OFDM (using OFDM transmission in the 2–11 GHz band)
4. WirelessMAN-OFDMA (using OFDM transmission and orthogonal frequency division multiple access (OFDMA) in the 2–11 GHz band)
5. WirelessHUMAN (for unlicensed frequency)

The use of orthogonal frequency division multiplexing (OFDM) (Hanzo and Wong, 2002) increases the data capacity and, consequently, the bandwidth efficiency with respect to classical SC transmission. This is obtained by the use of carriers very close to each other, the interference being avoided by the use of orthogonal carriers. In OFDMA, the subcarriers are divided into subsets, each subset representing a subchannel. The standard (IEEE, 2004) indicates that the OFDM symbol is divided into logical subchannels to support scalability, multiple access, and advanced antenna array processing capabilities. The OFDM physical layer model will be considered hereafter due to its frequent use and implementation simplicity.

A WiMAX transmitter consists of several blocks: a randomizer, forward error correction (FEC), an interleaver, and a modulator. They are applied in this order at transmission. The corresponding operations at the receiver are applied in reverse order.

The WirelessMAN air interface supports two mandatory FEC schemes: Reed–Solomon only and Reed–Solomon concatenated with block convolutional code (RS-CC). The concatenated coding scheme uses an inner convolutional code, which is similar to the convolutional code used in the IEEE 802.11a standard (IEEE, 1999). The standard also supports turbo block codes as an optional FEC scheme. FEC is essential for OFDM systems since it compensates for the bit errors that are inevitable due to the deep fades of the channel.
After RS-CC encoding, all encoded data bits are block interleaved, after which a 256-point FFT OFDM (in WiMAX-OFDM 802.16) or a 2048-point FFT OFDM (in WiMAX-OFDMA 802.16a) is applied. Such a system is very tolerant to the long multipath delays that occur in long-range, non-line-of-sight (NLOS) operation.

The standard supports four different modulation schemes. It supports higher order 16-QAM and 64-QAM schemes to maximize link throughput and also supports BPSK and QPSK for robustness and reliability.

The WiMAX/802.16 standard includes the two main duplexing modes: time division duplexing (TDD) and frequency division duplexing (FDD).

**Frequency Division Duplexing**

In this mode, the uplink and downlink channels are located on separate frequencies. A fixed-duration frame is used for both uplink and downlink transmissions. This facilitates the use of different modulation types. It also allows simultaneous use of both full-duplex SSs, which can transmit and receive simultaneously and, optionally, half-duplex SSs (H-FDD for half-duplex frequency division duplex), which cannot. A full-duplex SS is capable of continuously listening to the downlink channel, while a half-duplex SS can listen to the downlink channel only when it is not transmitting on the uplink channel.

**Time Division Duplexing**

In this case, the uplink and downlink transmissions share the same frequency but they take place at different times. A TDD frame has a fixed duration and contains one downlink and one uplink subframe. The frame is not necessarily divided into two equal parts. The TDD framing is adaptive in that the bandwidth allocated to the downlink versus the uplink can change. The split between the uplink and downlink is a system parameter and is controlled by the scheduler. TDD mode is the most frequently used mode of duplexing; a short detail on the structure of uplink and downlink subframes is provided in the next sections.

**Z.1.2 MAC Layer in WiMAX**

Since the BS has to manage several SSs, the MAC layer of WiMAX has some sophisticated bandwidth reservation and resource allocation mechanisms. WiMAX has divided the MAC layer into three sublayers, namely convergence sublayer (CS), common part sublayer (CPS), and security sublayer. The service-specific CS resides on the top of the MAC layer and mainly performs classification of higher-layer packet data units (PDUs) and payload header suppression (optional function). The CPS resides in the middle of the MAC layer and is responsible for connection establishment, resource allocation, and scheduling between the BS and SS. The security sublayer provides authentication, secure key exchange, encryption, and integrity control across the BWA system.
The SS establishes a connection with the BS using the contention slots in the uplink subframe (see Section AAAZZZ). Systems must follow a list of procedures for entering and registering a new SS on the network, as follow.

1. Scan for a downlink channel and establish synchronization with the BS. The frame start preamble is a repetitive, well-known pattern and the SS may use it to synchronize timing and frequency parameters with the BS.

2. Initial ranging allows an SS joining the network to acquire the correct transmission parameters, such as time offset, frequency, and transmitted power level, so that the SS can communicate with the BS. The SS uses a contention-based initial ranging interval in the uplink subframe (see Section AAAZZZ). Basic capabilities are then negotiated to exchange supported transmission parameters and a basic connection identifier (CID) and a primary CID are assigned.

3. The periodic ranging allows the SSs to adjust their transmission parameters so that they can maintain a communication quality with the BS. During this process, it acquires the correct timing offset of the network. The SS can then be aligned with the frame received from the BS (for the OFDM and OFDMA PHY layers). SSs can request power adjustments and/or downlink burst profile (modulation and coding scheme (MCS) changes. This is not a part of the network entry procedure but allows a survey of the physical link.

4. SS registration in the network is made when the capability of manageability is assigned to the SS. This is made when the SS sends its management capability (IP version, IP management mode, and MAC CRC support); when the BS recognizes the manageability, a secondary CID is assigned.

5. Establish IP connectivity (performed through DHCP).

6. Operational parameter configuration files are downloaded using TFTP with all the services supported.

7. Setup connections. At this last step, the network (through the BS) exchanges the information about the service flows preprovisioned for the SS.

Z.2 WiMAX PHY FRAME

The PHY frames are divided into downlink and uplink subframes for TTD mode. A downlink subframe is separated from an uplink subframe by a TTG gap, and the gap between the uplink subframe and the subsequent downlink subframe is called RTG gap as shown in Figure Z.1.

Z.2.1 OFDM PHY Downlink Subframe

The content of each downlink (DL) subframe is as follows.

- The **preamble** is used for synchronization; it is the first OFDM symbol of the frame.
- The **frame control head** (FCH) is one OFDM symbol long and follows the preamble. It provides the frame configuration information such as MAP
message length, coding scheme, and available subchannels. It also contains the **down link frame prefix** (DLFP) to specify the burst profiles and the length of burst profiles of one or several downlink bursts immediately following the FCH.

- The **downlink map** (DL-MAP) indicates the burst profile, location, and duration of zones within the DL frame. If present, the DL-MAP message is the first MAP PDU transmitted after FCH. It is BPSK modulated and protected with rate $1/2$ code by the mandatory coding scheme.

- The **uplink map** (UL-MAP) provides the subchannel and slot allocation and other control information for the uplink (IL) subframe. It should immediately follow DL-MAP (if one is transmitted) or the DLFP.

- The **downlink channel descriptor** (DCD) is transmitted by the BS at periodic intervals to define the characteristics of a downlink frame.

- The **uplink channel descriptor** (UCD) is transmitted by the BS at periodic intervals to define the characteristics of an uplink frame.

In the WiMAX standard, the scheduler manages the DL and UL subframes and controls how much resources are allocated in each direction. DL subframes begin by a frame control section that contains the DL-MAP for the current downlink frame as well as the UL-MAP for a frame in future. The DL-MAP informs all SSs of which part of the current frame they should listen to. The UL-MAP informs SSs of their transmission opportunities as a response to their dynamic bandwidth requests or on the basis of prior service agreements. These are followed by the transmission of the DL subframe and the UL subframe. The DL subframe is divided into a number of time division multiplex (TDM) portions, which are so-called burst profiles: all traffic associated with a particular burst profile is transmitted sequentially. Each burst profile is characterized by the use of a particular modulation and coding scheme (there are as many burst profiles as there are modulation and coding schemes), which are negotiated between the BS and SSs while establishing a connection. These are specified by the downlink interval usage code (DIUC).

Each burst can contain multiple concatenated fixed-size or variable-size packets or fragments of packets received from the higher layers. Each unused byte is set to stuff byte value (0xFF) (IEEE, 2004). Each burst profile has an
associated first come first served (FCFS) queue; each queue is checked to see if there are packets to transmit for that burst profile. If some packets need to be transmitted, the scheduler will continue to remove packets until there are no remaining resources available for that burst profile. Thus, the DL subframe is transmitted. Lengths of burst profiles are assigned by the scheduler and are communicated to users in the DL-MAP. Then, the DL subframe is transmitted.

SSs do not have to decode all the bursts, only the relevant ones; as the burst profile has already been negotiated while making connection between the BS and the SSs, the SS knows which portion of which burst it has to decode.

Z.2.2 OFDM PHY Uplink Subframe

The UL subframe is quite different as it requires coordination between the various SSs transmitting upwards. In this book, we consider only the downlink scenario and thus the DL subframes only. UL subframes are very shortly described. Their content is as follows.

1. Contention slots allowing initial ranging.
2. Contention slots allowing bandwidth requests.
3. One or more uplink PHY PDUs, each transmitted on a burst. Each of these PDUs is an uplink subframe transmitted from a different SS. A PDU may contain an SS MAC message.

Z.3 WiMAX MAC PDUs

As seen in Section Z.2, in DL subframes, several MAC PDUs are aggregated in bursts. Section 8.3, page 232, presents techniques for performing a reliable burst segmentation in the presence of noise. The content of each MAC PDU is introduced below.

Each MAC PDU begins with a fixed-size header, followed by a variable-length payload and an optional CRC. There are two types of MAC PDU headers.

- The generic MAC header (GMH) is the header of MAC frames containing either MAC management messages or CS data. The CS data may be user data or other higher layer management data. The generic MAC header frame is the only one used in downlink.
- The bandwidth request header (BRH) is not followed by any MAC PDU payload or CRC. This frame name has been introduced by the 802.16e amendment. Previously, in 802.16-2004, the BRH was defined to request additional bandwidths.

The content of these headers is presented in what follows.

Z.3.1 Generic MAC Header

As we are considering only the downlink case, where the connection is already established and MAC PDUs inside the BS contain only CS data, so only the
GMH is possible inside BB. Format of GMH as specified in IEEE 802.16-2004 (IEEE, 2004) is illustrated in Figure Z.2.

The various fields of a GMH are as follows.

- **Header Type (HT)** consists of a single bit set to 0 for GMH.
- **Encryption Control (EC)** field specifies whether the payload is encrypted or not and is set to 0 when the payload is not encrypted and to 1 when it is encrypted.
- **Type** field indicates the subheaders and special payload types present in the message payload (five possible subheader types).
- **Reserved (Rsv)** field is of two bits and is set to 00₂.
- **Extended Subheader Field (ESF)** field consists of a single bit set to 1 if the extended subheader is present and follows the GMH immediately (applicable in both the downlink and uplink).
- **CRC Indicator (CI)** field is a single bit set to 1 if a CRC is included and is set to 0 if no CRC is included.
- **Encryption Key Sequence (EKS)** field is two bits. It is the index of the **Traffic Encryption Key** (TEK) and initialization vector used to encrypt the payload. Obviously, this field is only meaningful if the EC field is set to 1.
- **Length (LEN)** field is 11 bits long. It specifies the length in bytes of the MAC PDU including the MAC header and the CRC, if present.
- **Connection IDentifier (CID)** field is 16 bits long and represents the connection identifier of the user.
- **Header Check Sequence (HCS)** field is 8 bits long and is used to detect errors in the header.

### Z.3.2 Bandwidth Request Header

Bandwidth request headers, shown in Figure Z.3, have the same size as generic MAC frame headers, but their content differs. A bandwidth request PDU consists only of a header and does not contain any payload. The fields of the header are provided below.

- **The HT field** is a single bit set to 1 for BRHs.
Format of WiMAX Packets

Bandwidth request header

(6 bytes)

<table>
<thead>
<tr>
<th>Bits</th>
<th>1</th>
<th>1</th>
<th>3</th>
<th>19</th>
<th>16</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>HT</td>
<td>EC</td>
<td>Type</td>
<td>Bandwidth request</td>
<td>CID</td>
<td>HCS</td>
<td></td>
</tr>
</tbody>
</table>

- The EC is a single bit set to 0, indicating no encryption.
- The type field is 3 bits long and indicates the type of BRH. It can take two values, namely 000 for incremental and 001 for aggregate bandwidth request.
- The bandwidth request (BR) field is 19 bits long and indicates the number of bytes requested.
- The CID field is 16 bits long and represents the CID of the connection for which uplink bandwidth is requested.
- The HCS field is 8 bits long and is used to detect errors in the header.

BIBLIOGRAPHY
