Annex B  
  
Specification of the *WirelessMAN-Advanced* [[1]](#footnote-1) radio interface technology

Background

IMT-Advanced is a system with global development activity and the IMT-Advanced terrestrial radio interface specifications identified in this Recommendation have been developed by the ITU in collaboration with the ***GCS[[2]](#footnote-2) Proponents*** and the ***Transposing Organizations***. It is noted from Document IMT-ADV/24, that:

– The ***GCS Proponent*** must be one of the ***RIT[[3]](#footnote-3)/SRIT[[4]](#footnote-4) Proponents*** for the relevant technology, **and** must have legal authority to grant to ITU‑R the relevant legal usage rights to the relevant specifications provided within a GCS corresponding to a technology in Recommendation ITU‑R M.2012

– A ***Transposing Organization*** must have been authorized by the relevant ***GCS Proponent*** to produce transposed standards for a particular technology, **and** must have the relevant legal usage rights.

It is further noted that ***GCS Proponents*** and ***Transposing Organizations*** must also qualify appropriately under the auspices of Resolution ITU‑R 9-4 and the ITU‑R “Guidelines for the contribution of material of other organizations to the work of the Study Groups and for inviting other organizations to take part in the study of specific matters (Resolution ITU‑R 9-4)”.

The ITU has provided the global and overall framework and requirements, and has developed the Global Core Specification jointly with the ***GCS Proponent***. The detailed standardization has been undertaken within the recognized ***Transposing Organizations*** which operate in concert with the ***GCS Proponent***. This Recommendation therefore makes extensive use of references to externally developed specifications.

This approach was considered to be the most appropriate solution to enable completion of this Recommendation within the aggressive schedules set by the ITU and by the needs of administrations, operators and manufacturers.

This Recommendation has therefore been constructed to take full advantage of this method of work and to allow the global standardization time‑scales to be maintained. The main body of this Recommendation has been developed by the ITU, with each Annex containing references pointing to the location of the more detailed information.

This Annex 2 contains the detailed information developed by the ITU and “IEEE” (the ***GCS Proponent***) and IEEE, ARIB, TTA, and WiMAX Forum (the ***Transposing Organizations***). Such use of referencing has enabled timely completion of the high-level elements of this Recommendation, with change control procedures, transposition, and public enquiry procedures being undertaken within the external organization. This information has generally been adopted unchanged, recognizing the need to minimize duplication of work, and the need to facilitate and support an ongoing maintenance and update process.

This general agreement, noting that the detailed information of the radio interface should to a large extent be achieved by reference to the work of external organizations, highlights not only the ITU’s significant role as a catalyst in stimulating, coordinating and facilitating the development of advanced telecommunications technologies, but also its forward-looking and flexible approach to the development of this and other telecommunications standards for the 21st century.

A more detailed understanding of the process for the development of this Recommendation may be found in Document IMT-ADV/24.

## 2.1 Overview of the radio interface technology

The *WirelessMAN-Advanced* radio interface specification is developed by IEEE. A complete end-to-end system based on *WirelessMAN-Advanced* is called WiMAX 2, as developed by the WiMAX Forum.

### 2.1.1 Overview of physical layer

The following sections highlights selected physical layer (PHY) features.

#### 2.1.1.1 Multiple access scheme

*WirelessMAN-Advanced* uses OFDMA as the multiple-access scheme in downlink (DL) and uplink (UL). It further supports both TDD and FDD duplex schemes including H-FDD operation of the mobile stations (MSs) in the FDD networks. The frame structure attributes and baseband processing are common for both duplex schemes. The OFDMA parameters are summarized in Table 2.1. *WirelessMAN-Advanced* also supports wider channel bandwidths, up to 160 MHz, with carrier aggregation. In Table 2.1, TTG and RTG denote transmit/receive and receive/transmit transition gaps, respectively.

TABLE 2.1

OFDMA parameters

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Nominal channel bandwidth (MHz) | | | 5 | 7 | 8.75 | 10 | 20 |
| Sampling factor | | | 28/25 | 8/7 | 8/7 | 28/25 | 28/25 |
| Sampling frequency (MHz) | | | 5.6 | 8 | 10 | 11.2 | 22.4 |
| FFT size | | | 512 | 1 024 | 1 024 | 1 024 | 2 048 |
| Subcarrier spacing (kHz) | | | 10.94 | 7.81 | 9.76 | 10.94 | 10.94 |
| Useful symbol time Tu (µs) | | | 91.429 | 128 | 102.4 | 91.429 | 91.429 |
| CP  Tg = 1/8 Tu | Symbol time Ts (µs) | | 102.857 | 144 | 115.2 | 102.857 | 102.857 |
| FDD | Number of OFDM symbols per 5 ms frame | 48 | 34 | 43 | 48 | 48 |
| Idle time (µs) | 62.857 | 104 | 46.40 | 62.857 | 62.857 |
| TDD | Number of OFDM symbols per 5 ms frame | 47 | 33 | 42 | 47 | 47 |
| TTG + RTG (µs) | 165.714 | 248 | 161.6 | 165.714 | 165.714 |
| CP  Tg = 1/16 Tu | Symbol time Ts (µs) | | 97.143 | 136 | 108.8 | 97.143 | 97.143 |
| FDD | Number of OFDM  symbols per 5 ms frame | 51 | 36 | 45 | 51 | 51 |
| Idle time (µs) | 45.71 | 104 | 104 | 45.71 | 45.71 |
| TDD | Number of OFDM symbols per 5 ms frame | 50 | 35 | 44 | 50 | 50 |
| TTG + RTG (µs) | 142.853 | 240 | 212.8 | 142.853 | 142.853 |
| CP  Tg= 1/4 Tu | Symbol Time Ts (µs) | | 114.286 | 160 | 128 | 114.286 | 114.286 |
| FDD | Number of OFDM symbols per 5ms frame | 43 | 31 | 39 | 43 | 43 |
| Idle time (µs) | 85.694 | 40 | 8 | 85.694 | 85.694 |
| TDD | Number of OFDM symbols per 5 ms frame | 42 | 30 | 37 | 42 | 42 |
| TTG + RTG (µs) | 199.98 | 200 | 264 | 199.98 | 199.98 |

#### 2.1.1.2 Frame structure

A superframe is a collection of consecutive equally-sized radio frames whose beginning is marked with a superframe header (SFH), which carries short-term and long-term system configuration information.

In order to decrease the air-link access latency, the radio frames are further divided into a number of subframes where each subframe comprises of an integer number of OFDM symbols. The transmission time interval (TTI) is defined as the transmission latency over the air-link and is equal to a multiple of subframe length (default is one subframe). There are four types of subframes:   
1) type-1 subframe, which consists of six OFDM symbols, 2) type-2 subframe, which consists of seven OFDM symbols, 3) type-3 subframe which consists of five OFDM symbols, and 4) type-4 subframe, which consists of nine OFDM symbols and can be used only in UL for channel bandwidth of 8.75 MHz when supporting legacy, i.e. OFDMA TDD WMAN, frames. The basic frame structure is shown in Fig. 2.1, where superframe length is 20 ms (comprised of four radio frames), radio frame size is 5 ms, and subframe length depends on channel bandwidth, length of cyclic prefix, and subframe type, i.e. type-1/2/3/4. The number of subframes per radio frame is predetermined to maximize the spectral efficiency for each frame configuration depending on channel bandwidth, length of cyclic prefix, subframe type, and duplex mode.

The concept of time zones applies to both TDD and FDD systems. These time zones are time-division multiplexed across time domain in the DL to support both new and legacy MSs. For UL transmissions both time and frequency-division multiplexing approaches can be used to support legacy and new terminals. The non-backward compatible improvements and features are restricted to the new zones. All backward compatible features and functions are used in the legacy zones.

Figure 2.1

Basic frame structure



#### 2.1.1.3 Physical structure and resource unit

The DL/UL subframes are divided into a number of frequency partitions, where each partition consists of a set of physical resource units (PRUs) over the available number of OFDM symbols in the subframe. Each frequency partition can include localized and/or distributed physical resource units. Frequency partitions can be used for different purposes such as fractional frequency reuse (FFR). The DL/UL resource partitioning and mapping is illustrated in Fig. 2.2. PRU is the basic physical unit for resource allocation that comprises 18 contiguous subcarriers by Nsym contiguous OFDM symbols where Nsym is 6, 7, 5 and 9 OFDM symbols for type-1, type-2, type-3 and type-4 subframes, respectively (type-4 is used only for UL). A logical resource unit (LRU) is the basic logical unit for distributed and localized resource allocations. LRU comprises of 18 × Nsym subcarriers.

Figure 2.2

Resource mapping process



#### 2.1.1.4 Resource mapping

The resource mapping process is defined as follows as illustrated in Fig. 2.2, where Pi denotes the i‑th frequency partition.

The PRUs are first subdivided into sub-bands and mini-bands where a sub-band comprises four adjacent PRUs and a mini-band comprises one PRU. The sub-bands are suitable for frequency selective allocations as they provide a contiguous allocation of PRUs in frequency. The mini-bands are suitable for frequency diverse allocations and are permuted in frequency (outer permutation in Fig. 2.2).

After frequency partitioning, the partition between localized or contiguous resource units (CRUs) and distributed resource units (DRUs) is done on a sector specific basis. All sub-bands are categorized into CRU, while mini-bands are categorized into either CRU or DRU. CRUs are used to achieve frequency-selective scheduling gain. A CRU comprises a group of subcarriers which are contiguous across frequency. DRUs are used to achieve frequency diversity gain. A DRU contains a group of subcarriers which are spread across a frequency partition. The sizes of the CRU and DRU are equal to that of PRU.

To form CRUs and DRUs, the subcarriers over the OFDM symbols of a sub-frame are partitioned into guard and used subcarriers. The DC subcarrier is not used. The used subcarriers are divided into PRUs. Each PRU contains pilot and data subcarriers. The number of used pilot and data subcarriers depends on MIMO mode, rank and number of multiplexed MS, as well as the number of OFDM symbols within a sub-frame.

The subcarrier (tone-pair) permutation defined for DRU of a DL frequency partition spreads the subcarriers across all the distributed resource allocations within a frequency partition. After mapping all pilots, the remaining used subcarriers are paired into contiguous subcarrier-pairs (tone‑pairs), and then are permuted to define the distributed logical resource units (DLRUs). The DL subcarrier permutation is performed per OFDM symbol within a sub-frame. Each of the DRUs of an UL frequency partition is divided into 3 tiles of 6 adjacent subcarriers over Nsym symbols. The tiles are collectively permuted across all the distributed resource allocations within a frequency partition to define DLRUs. The contiguous logical resource unit (CLRU) are obtained from direct mapping of CRUs. CLRUs are categorized into sub-band-based LRUs, so called sub-band logical resource unit (SLRU), and mini-band-based LRUs, so called mini-band logical resource unit (NLRU).

#### 2.1.1.5 Modulation and coding

Figure 2.3

Coding and modulation procedures



Figure 2.3 shows the channel coding and modulation procedures. A cyclic redundancy check (CRC) is appended to a burst (i.e. a physical layer data unit) prior to partitioning. The 16-bit CRC is calculated over the entire bits in the burst. If the burst size including burst CRC exceeds the maximum FEC block size, the burst is partitioned into KFB FEC blocks, each of which is encoded separately. If a burst is partitioned into more than one forward error correction (FEC) blocks, a FEC block CRC is appended to each FEC block before the FEC encoding. The FEC block CRC of a FEC block is calculated based on the entire bits in that FEC block. Each partitioned FEC block including 16-bit FEC block CRC has the same length. The maximum FEC block size is 4800 bits. Concatenation rules are based on the number of information bits and do not depend on the structure of the resource allocation (number of logical resource units and their size). *WirelessMAN-Advanced* utilizes the convolutional turbo code (CTC) with code rate of 1/3. The CTC scheme is extended to support additional FEC block sizes. Furthermore, the FEC block sizes can be regularly increased with predetermined block size resolutions. The FEC block sizes which are multiple of seven are removed for the tail-biting encoding structure. The encoder block depicted in Fig. 2.3 includes the interleaver.

Bit selection and repetition are used in *WirelessMAN-Advanced* to achieve rate matching. Bit selection adapts the number of coded-bits to the size of the resource allocation which may vary depending on the resource unit size and sub-frame type. The total subcarriers in the allocated resource unit are segmented to each FEC block. The total number of information and parity bits generated by FEC encoder are considered as the maximum size of circular buffer. Repetition is performed when the number of transmitted bits is larger than the number of selected bits. The selection of coded bits is done cyclically over the buffer. The mother-code bits, the total number of information and parity bits generated by FEC encoder, are considered as a maximum size of circular buffer. In case that the size of the circular buffer Nbuffer is smaller than the number of mother-code bits, the first Nbuffer bits of mother-code bits are considered as selected bits.

Modulation constellations of QPSK, 16QAM, and 64QAM are supported. The mapping of bits to the constellation point depends on the constellation-rearrangement (CoRe) version used for HARQ retransmission as described and further depends on the MIMO scheme. The QAM symbols are mapped into the input of the MIMO encoder. The sizes include the addition of CRC (per burst and per FEC block), if applicable. Other sizes require padding to the next burst size. The code rate and modulation depend on the burst size and the resource allocation.

Incremental redundancy HARQ (HARQ-IR) is used in *WirelessMAN-Advanced* by determining the starting position of the bit selection for HARQ retransmissions. Chase combining HARQ (HARQ‑CC) is also supported and considered as a special case of HARQ-IR. The 2-bit sub-packet identifier (SPID) is used to identify the starting position. The CoRe scheme can be expressed by a bit-level interleaver. The resource allocation and transmission formats in each retransmission in DL can be adapted with control signalling. The resource allocation in each retransmission in UL can be fixed or adaptive according to control signalling. In HARQ re-transmissions, the bits or symbols can be transmitted in a different order to exploit the frequency diversity of the channel. For HARQ retransmission, the mapping of bits or modulated symbols to spatial streams may be applied to exploit spatial diversity with given mapping pattern, depending on the type of HARQ-IR. In this case, the predefined set of mapping patterns should be known to the transmitter and receiver. In DL HARQ, the base station (BS) may transmit coded bits exceeding current available soft buffer capacity.

#### 2.1.1.6 Pilot structure

Transmission of pilot subcarriers in DL is necessary to allow channel estimation, channel quality measurement (e.g. channel quality indicator, CQI), frequency offset estimation, etc. To optimize the system performance in different propagation environments, *WirelessMAN-Advanced* supports both common and dedicated pilot structures. The classification of pilots into common and dedicated is done based on their usage. The common pilots can be used in distributed allocation by all MSs. Dedicated pilots can be used with both localized and distributed allocations. They are associated with user specific pilot index. The dedicated pilots are associated with a specific resource allocation, are intended to be used by the MSs allocated to specific resource allocation, and therefore shall be precoded or beamformed in the same way as the data subcarriers of the resource allocation. The pilot structure is defined for up to eight streams and there is a unified design for common and dedicated pilots. There is equal pilot density per spatial stream; however, there is not necessarily equal pilot density per OFDM symbols.

Figure 2.4

Pilot structures for 1, 2, 4, and 8 streams for Type-1 sub-frame



For the sub-frame consisting of 5 OFDM symbols, the last OFDM symbol is deleted. For the sub‑frame consisting of 7 OFDM symbols, the first OFDM symbol is added as the 7th OFDM symbol. To overcome the effects of pilot interference among the neighbouring sectors or BSs, an interlaced pilot structure is utilized by cyclically shifting the base pilot pattern such that the pilots of neighbouring cells do not overlap.

The UL pilots are dedicated to localized and distributed resource units and are precoded using the same precoding as the data subcarriers of the resource allocation. The pilot structure is defined for up to 4 transmit streams for SU-MIMO and up to 8 streams for CSM. When pilots are power-boosted, each data subcarrier should have the same transmission power across all OFDM symbols in a resource block. The 18 × 6 UL resource blocks use the same pilot patterns as the DL counterpart. The pilot pattern for 6 × 6 tile structure is used for DLRU only in case the number of streams is one or two and it is also shown in Fig. 2.4.

#### 2.1.1.7 Control channels

DL control channels carry essential information for system operation. Depending on the type of control signalling, information is transmitted over different time intervals (i.e. from superframe to sub-frame intervals). The system configuration parameters are transmitted at the superframe intervals, whereas control signalling related to user data allocations is transmitted at the frame/sub-frame intervals.

##### 2.1.1.7.1 Downlink control channels

Superframe Header (SFH)

The superframe header (SFH) carries essential system parameters and configuration information. The content of SFH is divided into two segments; i.e. primary and secondary SFHs. The primary SFH is transmitted every superframe, whereas the secondary SFH is transmitted over one or more superframes. The primary and secondary SFHs are located in the first sub-frame within a superframe and are time-division-multiplexed with the advanced preamble. The SFH occupies no more than 5 MHz bandwidth. The primary SFH is transmitted using predetermined modulation and coding scheme. The secondary SFH is transmitted using predetermined modulation scheme while its repetition coding factor is signalled in the primary SFH. The primary and secondary SFHs are transmitted using two spatial streams and space-frequency block coding to improve coverage and reliability. The MS is not required to know the antenna configuration prior to decoding the primary SFH. The information transmitted in the secondary SFH is divided into different sub-packets. The secondary SFH sub-packet 1 (SP1) includes information needed for network re-entry. The secondary SFH sub-packet 2 (SP2) contains information for initial network entry. The secondary SFH sub-packet 3 (SP3) contains remaining system information for maintaining communication with the BS.

Advanced MAP (A-MAP)

The advanced MAP (A-MAP) consists of both user-specific and non-user-specific control information. Non-user-specific control information includes information that is not dedicated to a specific user or a specific group of users. It contains information required to decode user-specific control signalling. User specific control information consists of information intended for one or more users. It includes scheduling assignment, power control information, and HARQ feedback. Resources can be allocated persistently to the MSs. Group control information is used to allocate resources and/or configure resources to one or multiple MSs within a user group. Within a subframe, control and data channels are frequency-division-multiplexed. Both control and data channels are transmitted on logical resource units that span over all OFDM symbols within a subframe.

Each DL subframe contains a control region including both non-user-specific and user-specific control information. All A-MAPs share a time-frequency region known as A-MAP region. The control regions are located in every subframe. The corresponding UL allocations occurs L subframes later, where L is determined by A-MAP relevance. The coding rate is predetermined for non-user-specific information while it is indicated by SFH for user-specific control information.

An A-MAP allocation Information Element (IE) is defined as the basic element of unicast service control. A unicast control IE may be addressed to one user using a unicast identifier or to multiple users using a multicast/broadcast identifier. The identifier is masked with CRC in the A-MAP allocation IE. It may contain information related to resource allocation, HARQ, MIMO transmission mode, etc. Each A-MAP IE is coded separately. Non-user-specific control information is encoded separately from the user-specific control information. In the DL subframes, frequency partition for reuse-1 and/or frequency partition for power-boosted reuse-3 may contain an A-MAP region. The A-MAP region occupies the first few DLRUs in a frequency partition. The structure of an A-MAP region is illustrated in Fig. 2.5. The resource occupied by each A-MAP physical channel may vary depending on the system configuration and scheduler operation. There are different types of A-MAPs as follows:

– **Assignment A-MAP** contains resource assignment information which is categorized into multiple types of resource assignment IEs (assignment A-MAP IE).

– **HARQ Feedback A-MAP** contains HARQ ACK/NACK information for UL data transmission.

– **Power Control A-MAP** includes fast power control command to MSs.

There are different assignment A-MAP IE types that distinguish between DL/UL, persistent/non-persistent, single user/group resource allocation, basic/extended IE scenarios.

Figure 2.5

A-MAP location and structure (example)



##### 2.1.1.7.2 Uplink control channels

Fast Feedback Channel (FBCH)

The UL fast feedback channel (FBCH) carries CQI and MIMO feedback.

CQI feedback provides information about channel conditions as seen by the MS. This information is used by the BS for link adaptation, resource allocation, power control, etc. The channel quality measurement includes both narrowband and wideband measurements. The CQI feedback overhead can be reduced through differential feedback or other compression techniques. Examples of CQI include effective carrier to interference plus noise ratio (CINR), band selection, etc.

MIMO feedback provides wideband and/or narrowband spatial characteristics of the channel that are required for MIMO operation. The MIMO mode, preferred matrix index (PMI), rank adaptation information, channel covariance matrix elements, and best sub-band index are examples of MIMO feedback information.

There are two types of UL FBCHs: a) primary fast feedback channel (P-FBCH) and b) secondary fast feedback channel (S-FBCH).S-FBCH can be used to support CQI reporting at higher code rate and thus more CQI information bits. FBCH is frequency-division-multiplexed with other UL control and data channels.

FBCH starts at a predetermined location, with the size defined in a DL broadcast control message. Fast feedback allocations to an MS can be periodic and the allocations are configurable. The specific type of feedback information carried on each fast feedback opportunity can be different. The number of bits carried in the fast feedback channel can be adaptive. For efficient transmission of feedback channels a mini-tile is defined comprising 2 subcarriers by 6 OFDM symbols. One LRU consists of 9 mini-tiles and can be shared by multiple FBCHs.

HARQ feedback channel

HARQ feedback (ACK/NACK) is used to acknowledge DL data transmissions. The UL HARQ feedback channel starts at a predetermined offset with respect to the corresponding DL transmission. The HARQ feedback channel is frequency-division-multiplexed with other control and data channels. Orthogonal codes are used to multiplex multiple HARQ feedback channels. The HARQ feedback channel comprises three distributed mini-tiles.

Sounding channel

The sounding channel is used by an MS to transmit sounding reference signals to enable the BS to measure UL channel conditions. The sounding channel may occupy either specific UL sub-bands or the entire bandwidth over an OFDM symbol. The BS can configure an MS to transmit the UL sounding signal over predefined subcarriers within specific sub-bands or the entire bandwidth. The sounding channel is orthogonally multiplexed (in time or frequency) with other control and data channels. Furthermore, the BS can configure multiple user terminals to transmit sounding signals on the corresponding sounding channels using code-, frequency-, or time-division multiplexing. Power control for the sounding channel can be utilized to adjust the sounding quality. The transmit power from each mobile terminal may be separately controlled according to certain CINR target values.

Ranging channel

The ranging channel is used for UL synchronization. The ranging channel can be further classified into ranging for non-synchronized and synchronized MSs. The ranging channel for non-synchronized MS(NS-RCH) is used for initial network entry and for handover to a target BS. The ranging channel for synchronized MS(S-RCH) is used for periodic ranging. In a femtocell, MSs shall perform initial ranging, handover ranging, and periodic ranging by using the S-RCH.

Bandwidth request (BR) channel

Bandwidth request (BR) channels are used to request UL grant. BRs are transmitted through BR preamble with or without messages. BR messages can include information about the status of queued traffic at the MS such as buffer size and quality of service parameters. Contention or non‑contention based random access is used to transmit BR information on this control channel.

The BR channel starts at a configurable location with the configuration defined in a DL broadcast control message. The BR channel is frequency-division-multiplexed with other UL control and data channels. A BR tile is defined as six contiguous subcarriers by six OFDMA symbols. Each BR channel consists of 3 distributed BR tiles. Multiple BR preamble can be transmitted on the same BR channel using code-division multiplexing.

#### 2.1.1.8 Power control

Power control mechanism is supported for DL and UL. Using DL power control, user-specific information with dedicated pilot is received by the terminal with the controlled power level. The DL advanced MAPs can be power-controlled based on the terminal UL channel quality feedback.

The UL power control is supported to compensate the path loss, shadowing, fast fading and implementation loss as well as to mitigate inter-cell and intra-cell interference. The BS can transmit necessary information through control channel or message to terminals to support UL power control. The parameters of power control algorithm are optimized on system-wide basis by the BS and broadcasted periodically.

In high-mobility scenarios, power control scheme may not be able to compensate the fast fading channel effect because of the variations of the channel impulse response. As a result, the power control is used to compensate the distance-dependent path loss, shadowing and implementation loss only.

The channel variations and implementation loss are compensated via open-loop power control without frequently interacting with the BS. The terminal can determine the transmit power based on the transmission parameters sent by the serving BS, UL channel transmission quality, DL channel state information, and interference knowledge obtained from DL. Open-loop power control provides a coarse initial power setting of the terminal when an initial connection is established.

The dynamic channel variations are compensated via closed-loop power control with power control commands from the serving BS. The BS measures UL channel state and interference information using UL data and/or control channel transmissions and sends power control commands to the terminal. The terminal adjusts its transmission power based on the power control commands from the BS.

#### 2.1.1.9 Downlink synchronization

*WirelessMAN-Advanced* utilizes a new hierarchical structure for the DL synchronization where two types of preambles, a) primary advanced preamble (PA-Preamble) and b) secondary advanced preamble (SA-Preamble), are transmitted (Fig. 2.6). One PA-Preamble symbol and two SA‑Preamble symbols exist within the superframe. The location of the A-Preamble symbol is specified as the first symbol of frame except for the last frame. PA-Preamble is located at the first symbol of second frame in a superframe while SA-Preamble is located at the first symbol of the first and the third frames. The PA-Preamble carries information about system bandwidth and carrier configuration. The PA-Preamble has a fixed bandwidth of 5 MHz. A frequency reuse of one is applied to the PA-Preamble in frequency domain. SA-Preamble is repeated once every two frames and spans the entire system bandwidth and carries the cell ID. A frequency reuse of three is used for this set of sequences to mitigate inter-cell interference. SA-Preamble carries 768 distinct cell IDs. The set of SA-Preamble sequences is partitioned and each partition is dedicated to specific BS type such as macro BS, femto BS, etc. The partition information is broadest in the secondary SFH and AAI-SCD message.

Figure 2.6

Structure of advanced preambles



#### 2.1.1.10 Multi-antenna techniques

##### 2.1.1.10.1 MIMO structure

*WirelessMAN-Advanced* supports several advanced multi-antenna techniques including single and multi-user MIMO (spatial multiplexing and beamforming) as well as a number of transmit diversity schemes. In single-user MIMO (SU-MIMO) scheme only one user can be scheduled over one (time, frequency, space) resource unit. In multi-user MIMO (MU-MIMO), on the other hand, multiple users can be scheduled in one resource unit. Vertical encoding utilizes one encoder block (or layer), whereas multi-layer encoding uses multiple encoders (or multiple layers). A layer is defined as a coding and modulation input path to the MIMO encoder. A stream is defined as the output of the MIMO encoder that is further processed through the beamforming or the precoder block. For spatial multiplexing, the rank is defined as the number of streams to be used for the user.

Figure 2.7

MIMO structure



The MIMO transmitter structure is shown in Fig. 2.7. The encoder block contains the channel encoder, interleaving, rate-matching, and modulating blocks per layer. The resource mapping block maps the complex-valued modulation symbols to the corresponding time-frequency resources. The MIMO encoder block maps the layers onto the streams, which are further processed through the precoder block. The precoder block maps the streams to antennas by generating the antenna-specific data symbols according to the selected MIMO mode. The OFDM symbol construction block maps antenna-specific data to the OFDM symbols. Table 2.2 contains information on various MIMO modes supported by *WirelessMAN-Advanced*.

TABLE 2.2

DL MIMO modes

| Mode index | Description | MIMO encoding format | MIMO precoding |
| --- | --- | --- | --- |
| Mode 0 | Open-Loop SU-MIMO (TX Diversity) | Space-Frequency Block Coding (SFBC) | Non-Adaptive |
| Mode 1 | Open-Loop SU-MIMO (Spatial Multiplexing) | Vertical Encoding | Non-Adaptive |
| Mode 2 | Closed-Loop SU-MIMO (Spatial Multiplexing) | Vertical Encoding | Adaptive |
| Mode 3 | Open-Loop MU-MIMO (Spatial Multiplexing) | Multi-layer Encoding | Non-Adaptive |
| Mode 4 | Closed-Loop MU-MIMO (Spatial Multiplexing) | Multi-layer Encoding | Adaptive |
| Mode 5 | Open-Loop SU-MIMO (TX Diversity) | Conjugate Data Repetition (CDR) | Non-Adaptive |

The minimum antenna configuration in the DL and UL is 2 × 2 and 1 × 2, respectively. For open-loop spatial multiplexing and closed-loop SU-MIMO, the number of streams is constrained to the minimum of number of transmit or receive antennas. The MU-MIMO can support up to 2 streams with 2 transmit antennas and up to 4 streams for 4 transmit antennas and up to 8 streams for 8 transmit antennas. Table 2.3 summarized the DL MIMO parameters for various MIMO modes.

TABLE 2.3

DL MIMO parameters

|  | Number of transmit antennas | STC rate per layer | Number of streams | Number of subcarriers | Number of layers |
| --- | --- | --- | --- | --- | --- |
| MIMO Mode 0 | 2 | 1 | 2 | 2 | 1 |
| 4 | 1 | 2 | 2 | 1 |
| 8 | 1 | 2 | 2 | 1 |
| MIMO Mode 1 and  MIMO Mode 2 | 2 | 1 | 1 | 1 | 1 |
| 2 | 2 | 2 | 1 | 1 |
| 4 | 1 | 1 | 1 | 1 |
| 4 | 2 | 2 | 1 | 1 |
| 4 | 3 | 3 | 1 | 1 |
| 4 | 4 | 4 | 1 | 1 |
| 8 | 1 | 1 | 1 | 1 |
| 8 | 2 | 2 | 1 | 1 |
| 8 | 3 | 3 | 1 | 1 |
| 8 | 4 | 4 | 1 | 1 |
| 8 | 5 | 5 | 1 | 1 |
| 8 | 6 | 6 | 1 | 1 |
| 8 | 7 | 7 | 1 | 1 |
| 8 | 8 | 8 | 1 | 1 |
| MIMO Mode 3 and  MIMO Mode 4 | 2 | 1 | 2 | 1 | 2 |
| 4 | 1 | 2 | 1 | 2 |
| 4 | 1 | 3 | 1 | 3 |
| 4 | 1 | 4 | 1 | 4 |
| 8 | 1 | 2 | 1 | 2 |
| 8 | 1 | 3 | 1 | 3 |
| 8 | 1 | 4 | 1 | 4 |
| MIMO Mode 4 | 4 | 2 and 1a | 3 | 1 | 2 |
| 4 | 2 and 1b | 4 | 1 | 3 |
| 4 | 2 | 4 | 1 | 2 |
| 8 | 2 and 1a | 3 | 1 | 2 |
| 8 | 2 and 1b | 4 | 1 | 3 |
| 8 | 2 | 4 | 1 | 2 |
| 8 | 1 | 8 | 1 | 8 |
| 8 | 2 and 1c | 8 | 1 | 7 |
| 8 | 2 and 1d | 8 | 1 | 6 |
| 8 | 2 and 1e | 8 | 1 | 5 |
| 8 | 2 | 8 | 1 | 4 |
| MIMO Mode 5 | 2 | 1/2 | 1 | 2 | 1 |
| 4 | 1/2 | 1 | 2 | 1 |
| 7 | 1/2 | 1 | 2 | 1 |
| a 2 streams to one MS and 1 stream to another MS, with 1 layer each. b 2 streams to one MS and 1 stream each to the other two MSs, with 1 layer each. c  2 streams to one MS and 1 stream each to the other six MSs, with 1 layer each. d 2 streams each to two MS and 1 stream each to the other four MSs, with 1 layer each. e 2 streams each to three MS and 1 stream each to the other two MSs, with 1 layer each. | | | | | |

The stream to antenna mapping depends on the MIMO scheme. In DL, the CQI and rank feedback are transmitted to assist the BS in rank adaptation, mode switching, and rate adaptation. For spatial multiplexing, the rank is defined as the number of streams to be used for each user. In FDD and TDD systems, unitary codebook based precoding is used for closed-loop SU-MIMO. In DL, an MS may feedback some information to the BS in closed-loop SU-MIMO such as rank, sub-band selection, CQI, precoding matrix index (PMI), and long-term channel state information.

In DL, the MU-MIMO transmission with up to two streams per user is supported. Beamforming is enabled with this precoding mechanism. *WirelessMAN-Advanced* has the capability to adapt between SU-MIMO and MU-MIMO in a predefined and flexible manner. Multi-BS MIMO techniques are also supported for improving sector and cell-edge throughput using multi-BS collaborative precoding, network coordinated beamforming, or inter-cell interference cancellation.

For UL MIMO, the BS will schedule users to resource blocks and determines the modulation and coding scheme (MCS) level and MIMO parameters (mode, rank, etc.). The supported antenna configurations include 1, 2, or 4 transmit antennas and more than two receive antennas. The UL MIMO modes and parameters are shown in Table 2.4 and Table 2.5, respectively.

TABLE 2.4

UL MIMO modes

|  |  |  |  |
| --- | --- | --- | --- |
| Mode Index | Description | MIMO Encoding Format | MIMO Precoding |
| Mode 0 | Open-Loop SU-MIMO (TX Diversity) | SFBC | Non-Adaptive |
| Mode 1 | Open-Loop SU-MIMO (Spatial Multiplexing) | Vertical Encoding | Non-Adaptive |
| Mode 2 | Closed-Loop SU-MIMO (Spatial Multiplexing) | Vertical Encoding | Adaptive |
| Mode 3 | Open-Loop Collaborative Spatial Multiplexing  (MU-MIMO) | Vertical Encoding | Non-Adaptive |
| Mode 4 | Closed-Loop Collaborative Spatial Multiplexing  (MU-MIMO) | Vertical Encoding | Adaptive |

TABLE 2.5

UL MIMO parameters

|  | Number of transmit antennas | STC rate per layer | Number of streams | Number of subcarriers | Number of layers |
| --- | --- | --- | --- | --- | --- |
| MIMO Mode 0 | 2 | 1 | 2 | 2 | 1 |
| 4 | 1 | 2 | 2 | 1 |
| MIMO Mode 1 | 1 | 1 | 1 | 1 | 1 |
| MIMO Mode 1 and MIMO Mode 2 | 2 | 1 | 1 | 1 | 1 |
| 2 | 2 | 2 | 1 | 1 |
| 4 | 1 | 1 | 1 | 1 |
| 4 | 2 | 2 | 1 | 1 |
| 4 | 3 | 3 | 1 | 1 |
| 4 | 4 | 4 | 1 | 1 |
| MIMO Mode 3 and MIMO Mode 4 | 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 1 | 1 | 1 |
| 2 | 2 | 2 | 1 | 1 |
| 4 | 1 | 1 | 1 | 1 |
| 4 | 2 | 2 | 1 | 1 |
| 4 | 3 | 3 | 1 | 1 |
| 4 | 4 | 4 | 1 | 1 |

The supported UL transmit diversity modes include 2 and 4 transmit antenna schemes with rate 1 such as space frequency block coding (SFBC) and 2 stream precoder. In FDD and TDD systems, unitary codebook-based precoding is supported. In this mode, the MS transmits a sounding reference signal in the UL to assist the UL scheduling and precoder selection in the BS. The BS signals the resource allocation, MCS, rank, preferred precoder index, and packet size to the MS. UL MU-MIMO enables multiple MSs to be spatially multiplexed on the same radio resources. Both open-loop and closed-loop MU-MIMO are supported. The MSs with single transmit antenna can operate in open-loop SU- or MU-MIMO mode.

### 2.1.2 Overview of MAC layer

The following sections describe selected MAC features.

#### 2.1.2.1 MAC addressing

*WirelessMAN-Advanced* defines global and logical addresses for an MS that identify the user and its connections during a session. The MS is identified by the globally unique 48-bit IEEE extended unique identifier assigned by the IEEE Registration Authority. The MS is further assigned the following logical identifiers: 1) A station identifier during network entry (or network re-entry), that uniquely identifies the MS within the cell, and 2) a flow identifier (FID) that uniquely identifies the control connections and transport connections with the MS. A temporary station identifier is used to protect the mapping between the actual station identifier during network entry. A deregistration identifier is defined to uniquely identify the MS within the set of paging group identifiers, paging cycle, and paging offset.

#### 2.1.2.2 Network entry

Network entry is the procedure through which an MS detects a cellular network and establishes a connection with that network. The network entry has the following steps (see Fig. 2.8):

– synchronization with the BS by acquiring the preambles;

– acquiring necessary system information such as BS and network service provider identifiers for initial network entry and cell selection;

– initial ranging;

– basic capability negotiation;

– authentication/authorization and key exchange;

– registration and service flow setup.

Figure 2.8

Network entry procedures



#### 2.1.2.3 Connection management and quality of service

A connection is defined as a mapping between the MAC layers of a BS and one (or several) MS. If there is a one-to-one mapping between one BS and one MS, the connection is called a unicast connection; otherwise, it is called a multicast or broadcast connection. Two types of connections are specified: control connections and transport connections. Control connections are used to carry MAC control messages. Transport connections are used to carry user data including upper layer signalling messages. A MAC control message is never transferred over transport connection, and user data is never transferred over the control connections. One pair of bi-directional (DL/UL) unicast control connections are automatically established when an MS performs initial network entry.

All the user data communications are in the context of transport connections. A transport connection is unidirectional and established with a unique FID. Each transport connection is associated with an active service flow to provide various levels of QoS required by the service flow. An MS may have multiple transport connections which have different set of QoS parameters, and each transport connection may have one or more sets of QoS parameters. The transport connection is established when the associated active service flow is admitted or activated, and released when the associated service flow becomes inactive. Transport connections can be preprovisioned or dynamically created. Pre-provisioned connections are those established by system for an MS during the MS network entry. On the other hand, the BS or the MS can cre­ate new connections dynamically if required.

#### 2.1.2.4 MAC header

*WirelessMAN-Advanced* specifies a number of efficient MAC headers for various applications comprising of fewer fields with shorter size compared to the generic MAC header of OFDMA TDD WMAN. The advanced generic MAC header in Fig. 2.9 consists of Extended Header Indicator, FID, and Payload Length fields. Other MAC header types include two-byte short-packet MAC header, which is defined to support small-payload applications such as VoIP and is characterized by small data packets and non-ARQ connection, Fragmentation extended header, Packing extended header for transport connections, MAC Control extended header for control connections, and Multiplexing extended header that is used when data from multiple connections associated with the same security association is present in the payload of the MAC protocol data unit (PDU).

Figure 2.9

Advanced generic MAC headers



#### 2.1.2.5 ARQ and HARQ functions

An ARQ block is generated from one or multiple MAC service data units (SDUs) or MAC SDU fragment(s). ARQ blocks can be variable in size and are sequentially numbered.

*WirelessMAN-Advanced* uses adaptive asynchronous and non-adaptive synchronous HARQ schemes in the DL and UL, respectively. The HARQ operation is relying on an N-process (multi-channel) stop-and-wait protocol. In adaptive asynchronous HARQ, the resource allocation and transmission format for the HARQ retransmissions may be different from the initial transmission. In case of retransmission, control signalling is required to indicate the resource allocation and transmission format along with other HARQ necessary parameters. A non-adaptive synchronous HARQ scheme is used in the UL where the parameters and the resource allocation for the retransmission are known *a priori*.

#### 2.1.2.6 Mobility management and handover

*WirelessMAN-Advanced* supports both network-controlled and MS-assisted handover (HO). As illustrated in Fig. 2.10, the handover procedures may be initiated by either MS or BS; the final handover decision and target BS selection may be made either by the serving BS or the MS. The MS executes the handover or cancels the procedure through HO cancellation message. The network re-entry procedures with the target BS, as shown in Fig. 2.10, may be optimized by target BS possession of MS information obtained from serving BS via core network. The MS may also maintain communication with serving BS while performing network re-entry at target BS as directed by serving BS.

Figure 2.10

Handover procedures



#### 2.1.2.7 Power management

*WirelessMAN-Advanced* provides power management functions including sleep mode and idle mode to mitigate power consumption of the MS. Sleep mode is a state in which an MS performs prenegotiated periods of absence from the serving BS. The sleep mode may be enacted when an MS is in the connected state. Using the sleep mode, the MS is provided with a series of alternative listening and sleep windows. The listening window is the time interval in which MS is available for transmit/receive of control signalling and data. The *WirelessMAN-Advanced* has the capability of dynamically adjusting the duration of sleep and listening windows within a sleep cycle based on changing traffic patterns and HARQ operations. When MS is in active mode, sleep parameters are negotiated between MS and BS. The base station instructs the MS to enter sleep mode. MAC management messages can be used for sleep mode request/response. The period of the sleep cycle is measured in units of frames or superframes and is the sum of a sleep and listening windows. During the MS listening window, BS may transmit the traffic indication message intended for one or multiple MSs. The listening window can be extended through explicit or implicit signalling. The maximum length of the extension is to the end of the current sleep cycle.

Idle mode allows the MS to become periodically available for DL broadcast traffic messaging such as paging message without registration with the network. The network assigns MSs in the idle mode to a paging group during idle mode entry or location update. If an MS is assigned to multiple paging groups, it may also be assigned multiple paging offsets within a paging cycle where each paging offset corresponds to a separate paging group. The assignment of multiple paging offsets to an MS allows monitoring of the paging messages at different paging offset when the MS is located in one of its paging groups. The distance between two adjacent paging offsets should be long enough so that the MS paged in the first paging offset can inform the network before the next paging offset in the same paging cycle occurs, thereby avoiding unnecessary paging in the next paging offset. The MS monitors the paging message during listening interval. The paging message contains identification of the MSs to be notified of pending traffic or location update. The start of the paging listening interval is calculated based on paging cycle and paging offset are defined in terms of number of superframes. The serving BS transmits the list of paging group identifiers (PGID) at the predetermined location at the beginning of the paging available interval. During paging available interval, the MS monitors the SFH and if there is an indication of any change in system configuration information, the MS will acquire the latest system information at the next instance of SFH transmission (i.e. next SFH). To provide location privacy, the paging controller assigns Deregistration identifiers to uniquely identify the MSs in the idle mode in a particular paging group.

An MS in idle mode performs location update, if either of these conditions are met, paging group location update, timer based location update, or power down location update. The MS performs the location update when the MS detects a change in paging group by monitoring the PGIDs, which are transmitted by the BS. The MS periodically performs location update procedure prior to the expiration of idle mode timer. At every location update including paging group update, the idle mode timer is reset.

#### 2.1.2.8 Security

Security functions provide subscribers with privacy, authentication, and confidentiality across *WirelessMAN-Advanced* network. The PKM protocol provides mutual and unilateral authentication and establishes confidentiality between the MS and the BS by supporting transparent exchange of authentication and authorization (EAP) messages.

The MS and the BS may support encryption methods and algorithms for secure transmission of MAC PDUs. *WirelessMAN-Advanced* supports selectively confidentiality or integrity protection over MAC control messages. Figure 2.11 shows the functional blocks of security architecture.

Figure 2.11

Functional blocks of security architecture



The security architecture is divided into security management and encryption and integrity logical entities. The security management functions include overall security management and control, EAP encapsulation/de-encapsulation, privacy key management (PKM) control, security association management, and identity/location privacy. To accomplish identity/location privacy, the MSID (i.e. MS MAC address) is not disclosed over the air even during network entry. The BS assigns a station identifier (STID) to the MS which is securely transmitted to the MS so that the MS’s identity and location can be hidden. The encryption and integrity protection entity functions include encryption of user data and authentication, control message authentication, message confidentiality protection.

## 2.2 Detailed specification of the radio interface technology

Detailed specifications described in this Annex are developed around a “Global Core Specification” (GCS)[[5]](#footnote-5), which is related to externally developed materials incorporated by specific references for a specific technology. The process and use of the GCS, references, and related notifications and certifications are found as Document IMT-ADV/24[[6]](#footnote-6).

The IMT-Advanced standards contained in this section are derived from the global core specification for *WirelessMAN-Advanced* contained at [http://ties.itu.int/u/ITU‑r/ede/rsg5/IMT-Advanced/GCS/WirelessMAN-Advanced/](http://ties.itu.int/u/itu-r/ede/rsg5/IMT-Advanced/GCS/LTE-Advanced/). The following notes apply to the sections below:

1) The identified relevant ***Transposing Organizations***[[7]](#footnote-7) should make their reference material available from their website.

2) This information was supplied by the ***Transposing Organizations*** and relates to their own deliverables of the transposed global core specification.

### 2.2.1 Description of the global core specification and the transposed standards

IEEE Std 802.16.1 is composed of IEEE Std 802.16.1-2012, as amended, consecutively, by IEEE Std 802.16.1b-2012 and IEEE Std 802.16.1a-2013. IEEE Std 802.16.1 is described in Section 2.2.1.1.

TABLE 2.6

Description of the *WirelessMAN-Advanced* GCS

|  |  |  |  |
| --- | --- | --- | --- |
| IEEE Std 802.16.1 Clause and Subject | IEEE Std 802.16.1-2012 | IEEE Std 802.16.1b-2012 | IEEE Std 802.16.1a-2013 |
| Clause 1: Overview | Base specification | Amended | Amended |
| Clause 2: Normative references | Base specification |  |  |
| Clause 3: Definitions | Base specification | Amended | Amended |
| Clause 4: Abbreviations and acronyms | Base specification |  | Amended |
| Clause 5: Service-Specific Convergence Sublayer | Base specification |  | Amended |
| Clause 6: *WirelessMAN-Advanced* Air Interface | Base specification | Amended | Amended |
| Annex A: Bibliography | Base specification |  |  |
| Annex B: Control Messages | Base specification | Amended | Amended |
| Annex C: Test Vectors | Base specification |  |  |
| Annex D: Supported frequency bands | Base specification |  |  |
| Annex E: Radio specifications | Base specification |  |  |
| Annex F: Default capability class and parameters | Base specification |  |  |



#### 2.2.1.1 IEEE Std 802.16.1

IEEE Std 802.16.1 is summarized here.

IEEE Std 802.16.1: IEEE Standard for WirelessMAN-Advanced Air Interface for Broadband Wireless Access Systems

This standard specifies the WirelessMAN-Advanced Air Interface, including the medium access control layer (MAC) and physical layer (PHY), of a broadband wireless access (BWA) system supporting multiple services

IEEE Std 802.16.1 is composed of IEEE Std 802.16.1-2012, as amended, consecutively, by IEEE Std 802.16.1b-2012 and IEEE Std 802.16.1a-2013.

##### 2.2.1.1.1 IEEE Std 802.16.1-2012

IEEE Standard for WirelessMAN-Advanced Air Interface for Broadband Wireless Access SystemsThis standard specifies the WirelessMAN-Advanced Air Interface, including the medium access control layer (MAC) and physical layer (PHY), of a broadband wireless access (BWA) system supporting multiple services.

##### 2.2.1.1.2 IEEE Std 802.16.1b-2012

IEEE Standard for WirelessMAN-Advanced Air Interface for Broadband Wireless Access Systems – Amendment 1: Enhancements to Support Machine-to-Machine Applications

This amendment specifies enhancements to the WirelessMAN-Advanced Air Interface. The enhancements provide improved support for machine-to-machine applications. As of the approval date, the applicable version of IEEE Std 802.16.1 is IEEE Std 802.16.1-2012, as amended by IEEE 802.16.1b-2012.

##### 2.2.1.1.3 IEEE Std 802.16.1a-2013

IEEE Standard for WirelessMAN-Advanced Air Interface for Broadband Wireless Access Systems – Amendment 2: Higher Reliability Networks

#### This amendment updates and expands IEEE Std 802.16.1, specifying enhanced mechanisms to support Higher Reliability Networks. As of the publication date, the current version of IEEE Std 802.16.1 is IEEE Std 802.16.1-2012, as amended by IEEE Std 802.16.1b-2012 and IEEE Std 802.16.1a-2013.2.2.1.2 Transposed standards

##### 2.2.1.2.1 Transpositions: IEEE



|  |  |  |  |
| --- | --- | --- | --- |
|  | Base standard per  IEEE Std  802.16.1-2012 | Amendment per  IEEE Std  802.16.1b-2012 | Amendment per  IEEE Std  802.16.1a-2013 |
| *Transposing Organization* | IEEE | IEEE | IEEE |
| *Document Number* | IEEE Std 802.16.1-2012 | IEEE Std 802.16.1b-2012 | IEEE Std 802.16.1a-2013 |
| *Version* | 2012 | 2012 | 2013 |
| *Issued Date* | 8 June 2012 | 30 August 2012 | 6 March 2013 |
| *Document* | <URL1>  [IEEE transposition of IEEE Std 802.16.1-2012] | <URL1b>  [IEEE transposition of IEEE Std 802.16.1b-2012] | <URL1a>  [IEEE transposition of IEEE Std 802.16.1a-2013] |

##### 2.2.1.2.2 [Other Transpositions]

1. Developed by IEEE as the *WirelessMAN-Advanced* specification incorporated in IEEE Std 802.16 beginning with approval of IEEE Std 802.16m. [↑](#footnote-ref-1)
2. Global Core Specifications. [↑](#footnote-ref-2)
3. Radio Interface Technology. [↑](#footnote-ref-3)
4. Set of Radio Interface Technologies. [↑](#footnote-ref-4)
5. A “GCS” (Global Core Specification) is the set of specifications that defines a single RIT, an SRIT, or a RIT within an SRIT. [↑](#footnote-ref-5)
6. Document IMT-ADV/24 is available on the ITU-R WP 5D webpage under the link “IMT-Advanced documents” (<http://www.itu.int/md/R07-IMT.ADV-C-0024/e>). [↑](#footnote-ref-6)
7. The following identified Transposing Organizations have provided their transposed sets of standards information contained in this section:

   • [Institute of Electrical and Electronics Engineers, Inc](http://www.itu.int/cgi-bin/htsh/mm/scripts/undefined). (IEEE).

   • Association of Radio Industries and Businesses (ARIB).

   • Telecommunications Technology Association (TTA).

   • WiMAX Forum. [↑](#footnote-ref-7)