The Implementation of IEEE 802.16m Protocol Module for ns-3 Simulator

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Abstract

This paper presents the first IEEE 802.16m medium access control (MAC) protocol module embedded in the network simulator version 3 (ns-3). The designed module provides a validation tool for researchers to verify simulated results related to the IEEE 802.16m. This module supports the basic MAC functions which includes an initial ranging (IR) function; four types of bandwidth request (BR) procedures; five types of standard-specified quality-of-service (QoS); a QoS-based transmission scheduler; an adaptive modulation and coding (AMC) selection function; a physical (PHY) layer with a channel propagation model. The designed module provides modification flexibility to adapt to other simulation modules. Various scenarios are simulated to show the capacity of the implemented IEEE 802.16m module in details. Results of different types of traffic are tested with the path loss effect on transmission to visualize the numeric capability of the module.

Keywords: 802.16m, medium access control (MAC), module, protocol, quality-of-service (QoS), scheduler

1. Introduction

In both fields of academia and industry, the use of a simulation tool is a cost efficient approach to visualize the potential of a new protocol or mechanism. The provision of a new simulation module in a common simulated platform provides a significant milestone for which researchers can benefit from their studies. The ease of use and customization are crucial when choosing an implementation platform.

The network simulator 3 (ns-3) \cite{1} fulfills these requirements. ns-3 is a C++ library which provides a set of network simulation models implemented as C++ objects which are wrapped through Python. The Python interpreter acts as a command receiver to configure and build simulated modules. The libraries of modules are linked after compilation. ns-3 is a successor of the famous network simulator 2 (ns-2) \cite{2}. In the last decade, ns-2 was the most popular network simulation tool. Due to its completeness in modules, researchers still find the needs to rely on ns-2.

However, since the module provided in ns-2 lacked portability to newer versions of operating system and compilers, it would be beneficial to choose a new platform such as ns-3 to develop a new communication protocol (in this case the IEEE 802.16m).

The IEEE 802.16m standard \cite{3} is one of the fourth generation (4G) mobile communication standards, which includes advanced techniques for nomadic wireless access. The design of the frame structure has completely been restructured from its previous design, the IEEE 802.16-2009 standard \cite{4} (a composition of the IEEE 802.16-2004 and 802.16e/f/g/i), as so does the control messages \cite{3}. Available IEEE 802.16-2004 simulators can be found in ns-2 \cite{5}, ns-3 \cite{6}, and NCTUns \cite{7}. In current trend of network performance analysis, these modules have already been outdated. The two main protocols that support the 4G mobile communication are the IEEE 802.16d and long-term evolution advanced (LTE-A) \cite{8}. While LTE-A simulation tools have been broadly developed in several platforms (LTE evolved packet core (EPC) network simulator (LENA) in ns-3 \cite{9}, MATLAB \cite{10}, and OMNeT++ \cite{11}), to the best of our knowledge, there is still no version of IEEE 802.16m module available in academia. The provision of another 4G network module could be a potential experimental value to be compared with the LTE-A simulation tool.

Based on the popularity and success of ns-3 and the lack of an open IEEE 802.16m simulation tool, we are motivated to contribute an open source IEEE 802.16m medium access control (MAC) protocol module in ns-3. In the developed module, the following functions are implemented: an initial network entry process, common and...
2. Background

2.1. Difference between Legacy IEEE 802.16 and 802.16m

This section introduces the difference between the legacy IEEE 802.16 and IEEE 802.16m protocols. To announce the frame structure and its modifications on system parameters, an elongated timed structure has been introduced, the super frame. A super frame consists of four 5 ms frames. The introduction of a super frame comes along with a super frame header (SFH). SFH provides synchronization and channel reuse of advanced mobile stations (AMSs). The SFH contains channel access information of the current advanced base station (ABS). SFH composes of a primary SFH (P-SFH) and three types of secondary SFHs (S-SFHs) subpacket (SP) information elements (IEs) (i.e., S-SFH SP1 IE, SP2 and SP3 IE). P-SFH defines the periodicity of the S-SFH. S-SFH SP1 IE contains information of network reentry. S-SFH SP2 IE contains information of initial network entry and discovery. S-SFH SP3 IE contains the remaining essential system information of ABS.

The mapping of the data burst allocation is also redefined to support the new frame structure. In the legacy IEEE 802.16, the mapping of the frame structure is contained in the downlink (DL) mapping message (DL-MAP) and uplink (UL) mapping message (UL-MAP). The IEEE 802.16m redefines these two mapping messages into an advanced mapping (A-MAP) message. A-MAP is structured with the following A-MAP IEs: hybrid automatic repeat request (HARQ) feedback A-MAP, power control A-MAP, non-user assignment A-MAP, and assignment A-MAP. The non-user assignment A-MAP contains each AMS's primary frequency partition to decode the assignment A-MAPs and HARQ feedback A-MAPs. The assignment A-MAP contains resource assignment information of all users. Assignment A-MAP contains DL, UL, and broadcast assignments. Assignment A-MAP IEs also includes the following A-MAP IEs: feedback allocation, code division multiple access (CDMA) allocation, group resource, feedback polling, and BR acknowledgement (BR-ACK).

User identification (ID) has also been modified to better categorize the user and its flows. In the setting for the legacy, the organization of ID is according to the connections of data burst (i.e., connection IDs (CIDs)). The assignment of these CIDs are more dynamic, since it defines the connection of a specific user’s service flow. However, this design lacks preciseness and organization. The IEEE 802.16m separates this CID into a service flow ID (FID) and a user or station ID (STID). The allocation of FID is categorized as unencrypted control connection (set as 0), encrypted control connection (set as 1), signaling header (set as 2), transport connection with default service flow (set as 3), and regular service transport connection (dynamic). STID is a 12 bits identifier that is also packaged in the cyclic redundant check (CRC). For each transmitted packet, the MAC protocol data unit (MPDU) includes an advanced generic MAC header (AGMH) that contains the FID of the connection and an CRC to which identifies the package designated for. Thus, as an example of the BR signaling header, the format includes an FID to which identifies as a control signal packet, a BR FID to which identifies as the flow requested, a STID to which identifies the user that requested it, and a BR size to which identifies the requested size.

The resource allocation scheme of IEEE 802.16m is distinctly different from the legacy IEEE 802.16. In IEEE 802.16m, the duration of one super frame is 20 ms. Each super frame contains four 5 ms frames. Each frame consists of 8 subframes. The transmission time of the scheduled resources is at the point of the end time of each subframe. The basic resource unit of IEEE 802.16m is a logical resource unit (LRU). Each flow can occupy several LRUs in a subframe. All scheduled resources are indicated in assignment A-MAPs.
2.2. Core Components of ns-3

Figure 1 shows the software organization of ns-3 [12]. ns-3 is built on two fundamental objects: the Node object and the NetDevice object. The basic computing device (i.e., a network node) in ns-3 is abstracted as a Node class. The Node class provides methods to manage the representations of computing devices in the network simulation. The NetDevice describes both the abstract of the proto-
and the simulated hardware. The NetDevice class is embedded in the Node class that enables the Node object to communicate with other nodes during simulation time. The NetDevice class is overloaded to specify according to the protocol when creating a module. To implement the ABS, the NetDevice is adopted to define the functionalities of an ABS, while the Node class is used to create an ABS object to be used in the simulation. In the module, the Node class is used to build the ABS and AMSs, and the implementation of MAC protocol is located in the NetDevice class. Since ns-3 is an event-driven network simulator, some basic ns-3 classes are used to control scheduled simulation events. Every event is triggered through the time function in ns-3. For simulation procedures, the Simulator object is in charge of controlling the events. Since the main focus of the implementation is in the MAC layer, functions such as routing, internet-stack, and applications are not tested in this module.

### 3. Component of the Implemented Module

The system architecture follows the IEEE 802.16m standard [3]. Figure 2 illustrates an overview of the designed IEEE 802.16m module on ns-3. The designed module contains most of the fundamental functions which characterizes the MAC layer of the standard. The MAC layer provides several algorithmic functionalities of the ABS and AMS.

#### 3.1. Time Control Functions

The module implementation follows the ns-3 simulator module design. Since ns-3 is a discrete-event network simulator, every action in the simulation is treated as an event. Every event is triggered with this virtual time function of ns-3. Several basic functions and components are declared in order to design a new module. Table 1 shows the event trigger functions created in the IEEE 802.16m module.

The design of the module decomposes a frame into several events, e.g., StartFrame, StartDLSubFrame, EndFrame, etc. The simulation starts by triggering the StartFrame event. The time interval of a frame is set to 5 ms as the standard had defined. StartFrame triggers StartDLSubFrame that creates a set of five DL subframes with CreateSubFrame. This procedure creates the DL of a frame. CreateSubFrame sets an end time for EndDLSubFrame. Thus, the duration of a DL subframe is equal to the point in time of EndDLSubFrame subtracting the point in time of StartFrame. When EndDLSubFrame is terminated, there is a transmit/receive transition gap (TTG) before StartULSubFrame. StartULSubFrame sets the start time to receive data from AMS. Similarly, EndULSubFrame sets the end time of the UL subframe. The interval between StartULSubFrame and EndULSubFrame is the transmission interval for AMS to transmit on the UL subframe. Concluding the above event configuration, EndULSubFrame sets the receive/transmit transition gap (RTG) and starts a new StartFrame event for the next iteration. This procedure repeats until the simulation terminates.

#### 3.2. Module Functionality

The class diagram of the module is shown in Figure 3. The unified modeling language (UML) is used to describe the IEEE 802.16m module. The diagram shows only significant variables and functions. As shown in the figure, the module is composed of several C++ classes. Every class represents a core component of the module. First, the description of each module functionalities is provided.

1) Simulation System Setup

<table>
<thead>
<tr>
<th>Class Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wimax16mNetDevice</td>
<td>Virtual WiMAX 16m Module.</td>
</tr>
<tr>
<td>ns-3 Node</td>
<td>Creation of ABS or AMS.</td>
</tr>
<tr>
<td>WimaxABSNetDevice</td>
<td>Creation of an Advanced Base Station.</td>
</tr>
<tr>
<td>WimaxAMSNetDevice</td>
<td>Creation of an Advanced Mobile Station.</td>
</tr>
<tr>
<td>Traffic Generator</td>
<td>Creation of ABS’s or AMS’s traffic.</td>
</tr>
<tr>
<td>Wimax16mPry</td>
<td>TX/RX data from AMS to/from ABS.</td>
</tr>
<tr>
<td>Wimax16mChannel</td>
<td>Perform transmission.</td>
</tr>
</tbody>
</table>

2) Base Station Functionalities

<table>
<thead>
<tr>
<th>Class Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMScRecord</td>
<td>Record information of each AMS the system</td>
</tr>
<tr>
<td>CAC</td>
<td>For future implementation of call admission control</td>
</tr>
<tr>
<td>DL-Scheduler</td>
<td>Downlink scheduling function.</td>
</tr>
<tr>
<td>UL-Scheduler</td>
<td>Uplink scheduling function.</td>
</tr>
<tr>
<td>Service Flow</td>
<td>Create service according to Traffic Generator.</td>
</tr>
<tr>
<td>Burst</td>
<td>Creation of MPDU burst including MAC control.</td>
</tr>
<tr>
<td>AMAP</td>
<td>Creation of A-MAP of each subframe.</td>
</tr>
</tbody>
</table>

3) Mobile Station Functionalities

<table>
<thead>
<tr>
<th>Class Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service Flow</td>
<td>Create service according to Traffic Generator.</td>
</tr>
<tr>
<td>Burst</td>
<td>Creation of MPDU burst including MAC control.</td>
</tr>
</tbody>
</table>
sent to the `Wimax16mABSNetDevice` class and the `Wimax16mAMSNetDevice` class accordingly.

The `Wimax16mABSNetDevice` class originates the frame structure for both the DL-Scheduler class and the UL-Scheduler class. The DL-Scheduler object generates traffic for each AMS according to a priority scheduling of UGS, rtPS, erTPS, nrtPS, and BE. This primitive scheduler schedules only one service at a time until the service have exhausted all transmission of this particular service. This primitive scheduler only provides simple unicast service for MAC control message and data transmission. At the start of the DL subframe, the scheduler generates the SFH. SFH carries essential system configuration information of the current ABS. The P-SFH is transmitted in every superframe, while subpackets of S-SFH are transmitted periodically. As we have discussed before, the time interval to trigger each event is based on units of frames. Thus, P-SFH is transmitted in every four frames, while S-SFH SP1, SP2, and SP3 is transmitted in every eight, sixteen, and thirty-two frames respectively.

The `Wimax16mAMSNetDevice` class is used to create the AMS objects. Simulation users can assign each of the AMS with a specific service, data size, starting time, and a generated MAC address. AMSs need to synchronize with ABS in order to identify the point of time of transmission. The synchronization is achieved upon receiving the preamble sequence and the SFH of the ABS. When both ABS and AMS are in synched, AMS awaits for ranging opportunity and sends the ranging code to ABS. The ranging code is a random generated number between 0 and 255. AMS achieves acceptance to ranging if no other AMS sends the same number. The ABS sends a ranging ACK back as response. After the AMS receives the ranging ACK, it sends a ranging request signal to the ABS. When the request is received, ABS assigns a temporary identification key to the AMS. The process follows by exchanging their

Figure 3: UML diagram of the implemented IEEE 802.16m module.
basic capability, authorization, and key management. The AMS completes registration with the ABS upon receiving a dedicated STID assigned by the ABS. BR is required in order to transmit any types of control messages. A BR is processed for each case of the network entry, except for ranging opportunity. The use of the state machines is implemented to control the network entry process of ABS and AMS.

Upon completion of network entry, a service flow connection is prepared for initiation. By sending a dynamic service add (DSA) request (DSA-REQ) from the AMS, ABS verifies whether to administer the AMS. When the ABS chooses to acknowledge this AMS, the ABS replies a DSA response (DSA-RSP) to confirm the connection establishment. The process is finalized with AMS sending a DSA acknowledgment (DSA-ACK) to acknowledge completion. In between transmission of data, service flow could be modified or deleted via dynamic service change (DSC) or dynamic service deletion (DSD) message respectively. This process creates a service flow for one connection.

4. Functionalities of the Implemented Module

4.1. Initial Network Entry Procedures

The network entry process is activated by the AMS. AMS starts by sending a ranging opportunity, which is a random sequence number between 0 and 255. This ranging opportunity is transmitted on the first UL subframe of the ranging channel. Upon receiving the ranging opportunity, the ABS replies with a ranging ACK. The following sequences include (1) ranging request and automatic adjustments, (2) basic capability negotiation, (3) authorization and key exchange, and finally (4) registration.

4.2. UL Bandwidth Request Procedures

The UL BR procedure is a mechanism that an AMS requests bandwidth for UL connections. The implemented module provides four types of BR schemes defined in the standard: unsolicited bandwidth grants (constant bit rate), polling procedures, contention-based procedures, and bandwidth stealing.

4.2.1. Unsolicited Bandwidth Grants

The unsolicited bandwidth grants is used when an AMS wants to transmit constant bit rate service such as the UGS. The AMS sends its essential information such as bit rate and transmission interval to the ABS. ABS acknowledges the time of grant and the amount of bandwidth requested for transmission.

4.2.2. Polling Procedures

The polling procedure is used when an AMS requests for rtPS, ertPS, and nrtPS services. The ABS sends a polling message periodically to AMSs that have polling related connections. When AMSs receive the polling messages, each AMS sends unicast request messages to the serving ABS through the BR channel. These requests contain the uplink data length of the connection. This mechanism ensures the ABS to receive the BR messages while avoiding contention requests from the AMSs.

4.2.3. Contention-Based Procedures

For contention-based BR, there are two types of BR mechanisms defined by the standard: the three-step BR mechanism and five-step BR mechanism. The five-step BR mechanism is an extension of the three-step BR mechanism. The difference between the three-step BR mechanism and five-step BR mechanism is the quick access message [3]. The quick access message is a set of predefined bandwidth allocation. In the three-step BR, it is assumed that the quick access message can be decoded by the ABS.

In case of contention access the ABS fails to decode the quick access message in the three-step BR mechanism, the ABS rolls back to the five-step BR mechanism. In the developed module, we only implement the fundamental five-step BR mechanism.

In a five-step BR mechanism, for each AMS that wants to transmit data, the AMS randomly chooses a BR tile to transmit a preamble. Each BR tile consists of 3 distributed BR tiles as shown in Figure 2. Each BR tile is made up of two portions: a preamble portion and a data portion. The BR tile is comprised of 6 contiguous subcarriers by 6 orthogonal frequency division multiple access (OFDMA) symbols [3], where the preamble portion is comprised of 4 subcarriers by 6 OFDMA symbols. In the IEEE 802.16m standard [3], it defines 256 available preamble codes for contention use. Therefore, each AMS has 3 x 256 opportunities in total for contention access at a time in each BR channel.

After sending the BR preamble, the serving ABS confirms the number of AMSs that are allowed within the system. The ABS replies BR ACK A-MAP IEs and grant bandwidths for AMSs to perform standalone BR headers. Each AMS sends the standalone BR header according to the parameter ABS has designated in the BR ACK A-MAP IE. When the serving ABS acquires the standalone BR header, it decides the amount of bandwidth to assign. The ABS will gradually grant UL transmission depending on its scheduling mechanism. To conclude this process, several AMSs have been granted for UL transmission and are able to begin transmission on the UL subframes.

4.2.4. Bandwidth Stealing

The IEEE 802.16m provides bandwidth stealing by sending an extended header in AGMH (i.e., piggyback). The piggyback BR mechanism is used by the AMS to request bandwidth for the same or different connections by adding a 32-bit long piggybacked BR extended header (PBREH) within an MPDU. The extended header contains an FID parameter that informs the ABS the connection to be requested or extended. Figure 4 shows the BR piggyback procedure.
4.3. Channel Model

The IEEE 802.16m module provides a basic PHY layer implementation which forwards bursts received by the MAC layer and neglects any interrelated PHY layer details. The channel object is built based on two basic PHY classes: the Wimax16mPhy class and the Wimax16mChannel class as shown in Figure 3. Figure 5 illustrates the flowchart of UL and DL traffic between the MAC and PHY layers.

A radio path loss model is included within the module. In [13], authors gave a network managed location identification scheme for IEEE 802.16m. According to the ITU-R M.1125 slow fading path loss model [14], the outdoor and pedestrian path-loss denoted as \( L(D_m) \), describes a path loss from an ABS to an AMS, which function is defined as

\[
L(D_m) = 40.0 \log_{10}(D_m) - 71.0 + 30.0 \log_{10}(f_c) \text{ (dB)},
\]

where \( f_c \) is the central frequency of operating radio frequency in MHz and \( D_m \) is the antenna distance between transmitter and receiver, i.e., ABS and AMS, in meters. In the module, we set the frequency as a constant value of 450 MHz which is the lowest frequency that IEEE 802.16m supports.

The modulation of each AMS is estimated by the location information of AMS to ABS [13]. The ABS then calculates the distance between the AMS and the path loss of its transmission [15, 16]. Transmit power of the ABS is set to 133 dB, because the simulation provides a worse case scenario of 1 km. The power of reception is estimated after the subtraction of path loss, so that the receive power of the AMS can be obtained. Depending on different reception power of AMs, the module categorizes AMs into three types of modulations: quadrature phase shift keying (QPSK), 16 quadrature amplitude modulation (16-QAM), and 64-QAM. When the received signal-to-noise ratio (SIR) is smaller than 10.5 dB, the modulation of the AMS is set to QPSK; when it is greater or equal to 10.5 dB and smaller than 16 dB, the modulation is set to 16-QAM; when it is greater than 16 dB, the modulation is set to 64-QAM [17].

4.4. Adaptive Modulation and Coding Function

The IEEE 802.16m system provides a variety of AMC schemes. The value of AMC is assigned according to the propagation effect and distance between the ABS and AMS. The position of a node is assigned by users as default setting of ns-3. The provision of a random deployment can be beneficial due to the simplicity of assigning nodes. In addition, for future implementation, mobility function can also be implemented along with the random deployment.

For both DL and UL connections, the modulation includes binary phase shift keying (BPSK), QPSK, 16-QAM, and 64-QAM, and BPSK is optional for OFDM-PHY. The coding rate includes 1/2, 2/3, 3/4, and 5/6. The coding rates act as convolutional codes that are used for error-correcting purpose. As an example, if the transmit coding rate is 1/2, this means that if there are \( m \) number of bits to be transferred, the actual transmittance data would be doubled to obtain a more reliable reception. The coding rate information is included within the DL/UL basic assignment A-MAP.

4.5. Scheduling Mechanism

The IEEE 802.16m standard defines two types of frames: the superframe and the subframe. A superframe (20 ms) consists of 4 frames and one frame (5 ms) consists of 8 subframes. Although the function of a frame is the same as the legacy, the subframe provides a shorter interval to transfer data. The use of superframe provides a new control message defined as SFH. In the preliminary module, a simple and basic frame structure which consists of only 10 MHz with 2048 FFT and 48 LRUs in TDD mode is implemented. The mapping of the frame structure is selected from two tables. The frame configuration and indexing table defines the number of DL and UL subframes and the intervals of each subframe. The number of physical resource units (PRUs) can be determined by the size of the bandwidth and the size of the fast fourier transform (FFT). The number of PRUs maps to LRUs in a manner of one to one and onto.

Several scheduling mechanisms have been proposed [18, 19]. However, in this paper, the major contribution does not focus on the scheduling mechanism, only a primitive QoS prioritized scheduling have been provided to support five types of IEEE 802.16m QoS classes as listed in Table 2. Interested readers can refer to [20] for further
investigation. The scheduler is modularized as a separate class for ease of use for future modifications or implementations. It increases flexibility and modularity of the module.

Figure 6, Figure 7, and Figure 8 illustrate the flowchart diagrams of the UGS, rtPS/ertPS/nrtPS, and BE scheduling procedures of the UL transmission, respectively. These five scheduling algorithms are executed by ABS. The UGS scheduling algorithm follows the constant bit rate (CBR) basis to serve the UGS connections. The available bandwidth is decremented as the number of served UGS connections increase. After one UGS connection is admitted, the UGS scheduler algorithm verifies whether it is possible to include the next UGS burst within this subframe. If it is possible, the scheduler updates the UL A-MAP which will appear in the first subframe of the next upcoming frame. This process is repeated until the current subframe cannot admit more UGS bursts, or when the the UGS service has been depleted. After one subframe has been scheduled, the data is transmitted to PHY. The next subframe scheduling is proceeded.

Figure 7 shows the rtPS, ertPS, and nrtPS scheduling algorithm used in the IEEE 802.16m module. The rtPS, ertPS, and nrtPS scheduling algorithms follow the standard procedure as described in the IEEE 802.16m standard [3]. If the rtPS connections are active (allowed for service), the rtPS scheduling algorithm checks the remaining quota of BR for data burst arrangement. In the module, rtPS is restricted to polling service only. ertPS, rtPS, and nrtPS have the ability to schedule for polling services, while contention polling service is designated for ertPS and nrtPS only. The procedure repeatedly assigns ertPS, rtPS, and nrtPS connections until the remaining quota of bandwidth is exhausted or all unserved connections get bandwidth. If there is remaining bandwidth, the AMS scheduler may assign piggyback service only for ertPS service. Finally, the scheduler arranges bandwidth for BE requests in a round-robin manner if the ABS still has bandwidth for allocation. The BE scheduling algorithm is shown in Figure 8.

Figure 9 shows an overview of the proposed scheduler. To begin with, the scheduler sorts all connections by their priority in descending order. After sorting the connections, the scheduler scans all the connections that need to be served in the particular interval. The highest serving priority of connection is the control signal connections followed by UGS, ertPS, rtPS, nrtPS, and BE sequentially. For each data burst that is created, an A-MAP is generated...
to direct AMSs to decode. The DL scheduler follows this priority sequence to schedule data bursts for AMSs. The UL scheduler has two types of sequence: the BR required service and the UGS. The bandwidth required services include ertPS, nrtPS, and BE for contention polling. The three types of service need an execution of a BR operation in order to gain the right to access the radio resource. The UGS follows the same scheduling procedures as described in the DL.

Within this frame structure, the description of the control message is first illustrated. Since the frame structure of the system has been redefined, the control messages are also restructured to adapt to the new MAC specifications. Although the procedures of these services differ, the basic functionalities of these services are the same, e.g., the network entry, BR, and service flow creation. The control message provides a more detailed control specification than the legacy, which means more information are transmitted in order to provide more specific commands. In the new frame structure, three new uplink control channels are introduced. The new control channels consist of a ranging channel, a BR channel, and fast feedback channels as shown in Figure 2. The ranging channel provides network entry opportunities for AMSs to compete for transmission of data. The BR channel provides BR opportunities. The fast feedback channels consist of the HARQ feedback channel and the feedback channel for wideband channel quality indication (CQI), subband, and multiple input multiple output (MIMO) feedback. The control channels are dedicated in the first uplink subframe of every frame which consists of 12 LRUs.

The mapping of the messages also has a new specification for packaging. Each MPDU is packed with an AGMH and a CRC. The AGMH identifies each packet’s service flow (or FID), while the CRC identifies the ID of the sender (or STID). The CRC consists of 1 bit masking prefix, 3 bits message type indicator, and 12 bits masking code. For unicast data transmission, the 12 bits masking code represents the STID of the AMS. After packaging the header and the CRC, the ABS needs to notify the AMS to receive this information through A-MAP. For basic DL transmission, the format is DL basic assignment A-MAP IE; likewise, for basic uplink transmission, the format is UL basic assignment A-MAP IE. In order to identify the location and allocation size, a resource index is present in all A-MAP formats.

After discussing the data format of the MPDUs, the calculation of allocation size (burst) is required in order to describe the complete frame structure of IEEE 802.16m. There are three basic variables: i-sizeoffset as \( I_0 \), i-minimalsize as \( I_m \), and index as \( I_a \). These three variables are decided by three tables shown in Table 960, Table 961, and Table 962 of the IEEE 802.16m standard [3], respec-
respectively. At first, the variable $I_d$ is obtained by the actual size of a data burst. Followed by the $I_o$ variable is obtained by the allocation size and modulation (The modulation is numbered as 1 for BPSK, 2 for QPSK, 4 for 16-QAM, and 6 for 64-QAM). With these two values, a range of $I_o$ is obtained. Depending on the signal decency, users can chose one of the following value, although the primary design is to assign $I_o$ according to the distance between AMS and ABS. Finally, the variable $I_m$ is calculated as $I_m = I_d - I_o$. The final value obtained is mapped to the table, and the allocation size (in LRUs) of the burst can be determined.

5. Simulation Results

To demonstrate the capability of our implemented IEEE 802.16m module, we configure several scenarios to perform stress tests. Detailed system configuration and parameters are listed in Table 3. In the simulation, we use the developed random deployment function to randomly distribute 12 AMSs around a center ABS. The radius of radio coverage of an ABS is set as 1500 meters. Figure 10 shows one snapshot of the tested scenarios. The individual transmission data rate to each AMS is determined by the developed AMC function according to its distance from the ABS.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of AMSs</td>
<td>4 ~ 16</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>10 MHz</td>
</tr>
<tr>
<td>Transmit frequency</td>
<td>450 MHz</td>
</tr>
<tr>
<td>Transmit power of ABS</td>
<td>40 dBm</td>
</tr>
<tr>
<td>Thermal noise</td>
<td>$-99$ dBm</td>
</tr>
<tr>
<td>Frame duration</td>
<td>5 ms</td>
</tr>
<tr>
<td>Subframes in one frame</td>
<td>8</td>
</tr>
<tr>
<td>Number of LRUs in subframe</td>
<td>48</td>
</tr>
<tr>
<td>DL/UL subframe ratio</td>
<td>5 : 3</td>
</tr>
<tr>
<td>Acceptance of QPSK</td>
<td>5 dB</td>
</tr>
<tr>
<td>Acceptance of 16-QAM</td>
<td>10.5 dB</td>
</tr>
<tr>
<td>Acceptance of 64-QAM</td>
<td>16 dB</td>
</tr>
</tbody>
</table>

Table 3: System Configuration and Parameters

In the simulation, 5 types of service flows are considered: UGS, erTPS, rtPS, nrtPS, and BE. All connections are generated from the traffic generator for both the AMSs and ABS designated by user settings. The traffic from the ABS is treated as DL traffic to AMSs; in contrast, the traffic from the AMSs is the UL traffic to the ABS. In our simulation, for UGS traffic, there are 6 UGS service flows for each AMS, 3 of 6 for DL and the others for UL. For variable bit rate service, there are 6 rtPS service flows, 6 erTPS service flows, 6 nrtPS service flows and 4 BE service flows, half of them for DL and the other half for UL. Thus, the priority order of the assigned traffic is UGS, erTPS, rtPS, nrtPS, and BE as mentioned before.

Figure 11 illustrates the transmitted bits in an 100 ms time interval. The transmitted bits range is between 90 and 240 Kbps. There is no traffic from 0 second to 1 second, because in this simulation the traffic starts from 1 second and ends at 15 seconds. The number of users is 12 AMSs. Since in our simulation, the traffic generator creates data every one second, the results show a one second repetition. The simulation then follows each of the scheduling algorithms. We can see that the first and third 100 ms, the transmit bits are higher. This shows that at that particular interval, high modulation AMSs are being served; thus, it provides a higher data rate. Similarly, at the last few intervals, AMSs with lower modulation are being served with a BE service.

Figure 12 illustrates the average throughput (bits) per subframe. We can see that QPSK can only transmit 400 bits per subframe, 16-QAM can transmit around 1800 bits per subframe, while 64-QAM 9000 bits per subframe. This experiment shows that the developed module has the capability to reflect the distance set in the simulation to the corresponding AMC schemes. Figure 12 verifies the correctness of the AMC function in the module and the transmission rate of each corresponding modulation schemes.

Figure 13 illustrates the throughput with various distances of AMSs. In the figure, $d$ is the distance between
the ABS and AMSs. When AMSs are further away from the ABS, the path loss value is higher. With this channel model, the solid line, dashed line, and dotted line, each of which represents 64-QAM, 16-QAM, and QPSK, respectively. The figure shows that, for 64-QAM, the distance can go up to 724 meters. This shows that the channel model provides an almost light of sight (LOS) propagation, which provides higher modulation for most AMSs. The range for 16-QAM is only 270 meters (i.e., 994 – 724). Results show that as time passes the threshold of QPSK is around 500 Kbps, 16-QAM is around 2500 Kbps, and 64-QAM is around 1600 to 1700 Kbps.

Figure 14 illustrates the average contention delay under a given number of AMSs. The contention delay is defined as the time difference between the point of time the AMS sends the BR preamble to the ABS and the point of time the AMS gets the response from the ABS. In this simulation, the number of AMSs is 10. Figure 14 shows that the average contention delay increases with the increase of the number of AMSs. The cause of contention delay increase is due to collisions during the BR process. With the increasing number of AMSs, the probability of collisions will also increase because the possibility of sending BR preambles by AMSs becomes higher. Since the cause of contention delay is highly related to the number of slots available for BR, the access delay would then grow greatly when the number of AMSs increases to a degree.

Figure 15 illustrates the MAC delay versus the increase of the number of AMSs on five different QoS service types. The MAC delay is defined as the time difference between the point of time the packet waits for service and the point of time the packet starts transmission. As the figure shows, the MAC delay of UGS is always around zero because it has the highest priority (bandwidth preemption). The ertPS, rtPS, and nrtPS have a relatively close delay time, since the services are scheduled requiring a bandwidth request for each service. BE service, which has the lowest priority, has the highest MAC delay. The simulation result is in accordance with our expectation.

Figure 16 illustrates the average queuing delay versus different numbers of AMSs with different types of services. The queuing delay is defined as the time difference between the point of time the packet arrives and the point of time the packet gets MAC services. As the figure shows, the queuing delay of UGS is also close to zero. This is due to bandwidth preemption. The ertPS, rtPS, nrtPS, and BE increase by the margin because of the serving priority. As the simulation results show, as the amount of AMSs increase, the queuing delay has a linear increase with an increase of slope for lower priority services.

6. Conclusion

In this paper, we have presented a detailed design and implementation of the 802.16m simulation module for ns-3.
The designed module is based on the IEEE 802.16m standard and the ns-3 version 3.19. The design of the module follows the object-oriented software development methodology and utilizes UML for modeling. The implemented module comprises key components of the 802.16m MAC layer, including a network entry function, several types of BR mechanisms, a simple scheduler based on priorities of QoS types, and an AMC function reflecting the distance. These functions are capable of providing fundamental system performance evaluation of the IEEE 802.16m protocol. Interested researchers can combine and extend these functions for their research works. The implemented module consists of basic functions for future enhancement. Since the module is implemented according to the standard release process of ns-3, it is highly compatible with other modules in ns-3 and additional functions, such as ARQ, HARQ, handover, and sleep mechanisms, can be easily extended within this module.

Figure 15: MAC delay versus different numbers of AMSs with different service types.

Figure 16: Queuing delay versus different numbers of AMSs with different service types.

References


