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The Design and Implementation of WiMAX Module for ns-2 Simulator

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ABSTRACT

The network simulator 2 (ns-2) is a popular and powerful simulation tool for the simulation of packet-switched networks, which provides substantial support for simulation of TCP, routing, and MAC protocols over wired and wireless networks, such as wireless LANs, mobile ad hoc networks (MANETs), and satellite communications, etc, and is widely used in both academia and industry. Although many protocol modules have been implemented in the ns-2, the IEEE 802.16 broadband wireless access networks (BWANs) or WiMAX module has not been contributed yet. Thus, in this paper, we present our detailed design and implementation of the WiMAX module based on the IEEE 802.16 standard with the point-to-multipoint (PMP) mode for the ns-2. The implemented module comprises fundamental functions of the service-specific convergence sublayer (CS), the MAC common part sublayer (CPS), and the PHY layer. A simple call admission control (CAC) mechanism and the scheduler are also included in this module.

Keywords

Broadband, MAC, module, network, simulator, WiMAX.

1. INTRODUCTION

Broadband wireless access (BWA) has been receiving much more attentions recently [6, 7, 10]. Since the number of wireless network devices will soon surpass the number of wired network devices, research into wireless networks is being more recognized. Fixed BWA systems, such as the local multipoint distribution service (LMDS), provide multimedia services to a number of discrete subscriber sites with IP and offer numerous advantages over wired IP networks. This is accomplished by using base stations (BSs) to provide network access services to subscriber sites based on the IEEE 802.16 WirelessMAN standard. First published in April 2002, IEEE 802.16 standard has recently been updated to IEEE 802.16-2004 [1] (approved in June 2004). The standard focuses on the "first-mile/last-mile" connection in wireless metropolitan area networks (WMANs) [5].

Its purpose is to facilitate the optimal use of bandwidth 2–66 GHz as well as the interoperability among devices from different vendors. Typical channel bandwidth allocations are 20 or 25 MHz (United Stats) or 28 MHz (Europe) in 10–66 GHz, or various channel bandwidths among 1 to 30 MHz in 2–11 GHz [2]. The progress of the standard has been fostered by the keen interest of the wireless broadband industry to capture the emerging WiMAX (worldwide interoperability for microwave access) market; the next-wave wireless market that aims to provide wireless broadband access services. IEEE 802.16 is the current trends on WiMAX. The WiMAX Forum, formed in 2003, is promoting the commercialization of IEEE 802.16 and the European Telecommunications Standard Institute's (ETSI's) high performance radio MANs (HyperMANs). It provides one of potential solutions to B3G/4G architecture.

The IEEE 802.16 standard defines the specifications related to the service-specific convergence sublayer (CS), the MAC common part sublayer (CPS), the security sublayer, and the PHY layer. The MAC management messages, such as the ranging request/response (RNG-REQ/RNG-RSP), the downlink/uplink channel descriptor (DCD/UCD), the downlink/uplink map (DL-MAP/UL-MAP), and so forth are implemented to operate the WiMAX networks. All operations between the base station (BS) and subscriber stations (SSs) over a *superframe* interval follow the compulsory procedures of the 802.16 standard. The detailed descriptions of IEEE 802.16 can be found in [1, 2, 3].

The most popular network simulator used by the academia and industry is the network simulator 2 (ns-2) [11], which has become the *de facto* standard for the simulation of packet-switched networks. Specifically, more and more published network studies and investigations take ns-2 as their evaluation tool to verify their work. Although there is another force that investigates the IEEE 802.16-based simulator [8],

*Correspondence should be addressed to J. Chen (e-mail: jhchen@mail.cgu.edu.tw). For the WiMAX module download, please visit the web site at http://ndsl.csie.cgu.edu.tw /wimax_ns2.php.

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this simulator is not public. The ns-2 is roughly composed of various traffic models, transport-layer protocols, network-layer protocols, medium access control (MAC) layer protocols, and more. These components enable ns-2 to simulate different types of networks and their topologies. Researchers can benefit from these preliminary tests on their investigation and find out the drawbacks of their new design in the early stage efficiently.

However, as far as the authors are aware, no WiMAX or IEEE 802.16 module has been contributed to ns-2. Due to this reason, in this paper, we design and implement the WiMAX module for ns-2. The developed WiMAX module is focused on MAC protocol development and inherited from the original MAC class in ns-2. This module is based on IEEE 802.16 point-to-multipoint (PMP) mode, which means that one BS can serve multiple subscriber stations (SSs) concurrently. We choose the orthogonal frequency-division multiple access (OFDMA) scheme for the physical (PHY) layer. Based on the OFDMA PHY specifications, it has been of major interest for both wireless applications due to its high date rate transmission capability and its robustness to multipath delay spread [9].

In addition, we adopted the unified modeling language (UML) to design and analyze the developed WiMAX module in the early stages. The UML allows programmers to easily get the visualization and analysis of the required system models in the WiMAX module. The UML is also applicable to the context of a paradigm that enhances the capability of modeling the program and simplifies the management and maintenance of the module.

The remainder of this paper is organized as the following: Section 2 takes an overview of the IEEE 802.16 architecture; Section 3 describes all classes built in the module and detailed operations of each component; Section 4 demonstrates the system parameters used in the WiMAX module and some examples of the usage of this module; Section 5 presents our conclusions of this paper.

2. AN OVERVIEW OF THE IEEE 802.16 ARCHITECTURE

The section briefly summarizes the operations of MAC and PHY layers in the IEEE 802.16 standard. Fig. 1 illustrates the architecture of IEEE 802.16. The CS provides any transformation or mapping of external network data that is received through the CS service access point (SAP) and converts them into MAC service data units (MSDUs) received by the MAC layer through the MAC SAP. This sublayer includes classifying external network SDUs and associating them to the proper MAC service flow identifier (SFID) and connection ID (CID). In addition, it may also include the payload header suppression (PHS) function.

The MAC CPS provides the core MAC functionality of system access, bandwidth allocation, scheduling, contention mechanism, connection establishment, and connection maintenance. It receives data from various CSs through the MAC SAP, which is classified to particular MAC connections. The IEEE 802.16-2004 standard supports four quality-of-service scheduling types: unsolicited grant service (UGS) for the constant bit rate (CBR) service, real-time polling service (rtPS) for the variable bit rate (VBR) service, non-real-time polling service (nrtPS) for non-real-time VBR, and best effort service (BE) for service with no rate or delay requirements. In 802.16e standard, there is an additional service type called extended real-time polling service (ertPS) for voice over IP (VoIP) service with silence suppression.

These quality-of-service (QoS) classes are associated with certain predefined sets of QoS-related service flow parameters, and the MAC scheduler supports the appropriate data handling mechanisms for data transport according to each QoS classes. The upper-layer protocol data units (PDUs) are inserted into different levels of queues with an assigned CID in the MAC layer after the SFID-CID mapping. These data packets in these queues are treated as MSDUs and then will be fragmented or packed into various sizes according to the MAC scheduling operations. They will be processed by a selective repeat automatic repeat request (ARQ) block mechanism if the ARQ-enabled function is on.

For the UL traffic, each SS should range to the BS before entering the system. During the initial ranging period, the SS will request to be served in the DL via the particular burst profile by transmitting its choice of DL interval usage code (DIUC) to the BS. Afterwards, the BS will command the SS to use a particular uplink burst profile with the allocated UL interval usage code (UIUC) with the grant of SS in UL-MAP messages. The DL-MAP and UL-MAP contain the channel ID and the MAP information elements (IEs) which describes the PHY specification mapping in the UL and DL respectively. They are based on the different PHY specifications, such as single carrier (SC), single carrier access (SCa), OFDM, and OFDMA. The burst profile includes the DIUC, UIUC, and the type-length-value (TLV) encoded information. The TLV encoded information will notify the PHY layer of the modulation type, FEC code type, and encoding parameters. The MAC data payload is packed by these encoding type.

The PHY layer requires equal radio link control (RLC), which is the capability of the PHY layer to transit from one burst profile to another. The RLC begins with the periodic BS broadcasting of the burst profiles which have been chosen for the downlink or the uplink connections. After the initial determination of downlink and uplink burst profiles between the BS and a particular SS, RLC continues to monitor and control the burst profiles. The SS can range with the RNG-REQ message to request a change in the downlink burst profile. The channel measurements report request (REP-REQ) message will be used by a BS to request signal-to-noise ratio (SNR) channel measurements reports. The channel measurement report response (REP-RSP) message is used by the SS to respond the channel measurements listed in the received REP-REQ.

The IEEE 802.16 uses the frame-based transmission architecture where the frame length is variable. Each frame is called a superframe and is divided into two subframes: the DL subframe and the UL subframe. In this paper, we are focusing the frame structure of the OFDMA-PHY in time division duplex (TDD) mode. A DL subframe consists of DL subframe prefix to specify the modulation and coding (in PHY mode), the length of the first DL burst, and the broadcasted MAC control messages, e.g., the downlink channel descriptor (DCD) and the uplink channel descriptor (UCD). Both of them define the characteristics of the physical channels by comprising the detail information of the DL burst profile and the UL burst profile.

Although IEEE 802.16 defines the connection signaling (connection requests and responses) between SS and BS, it

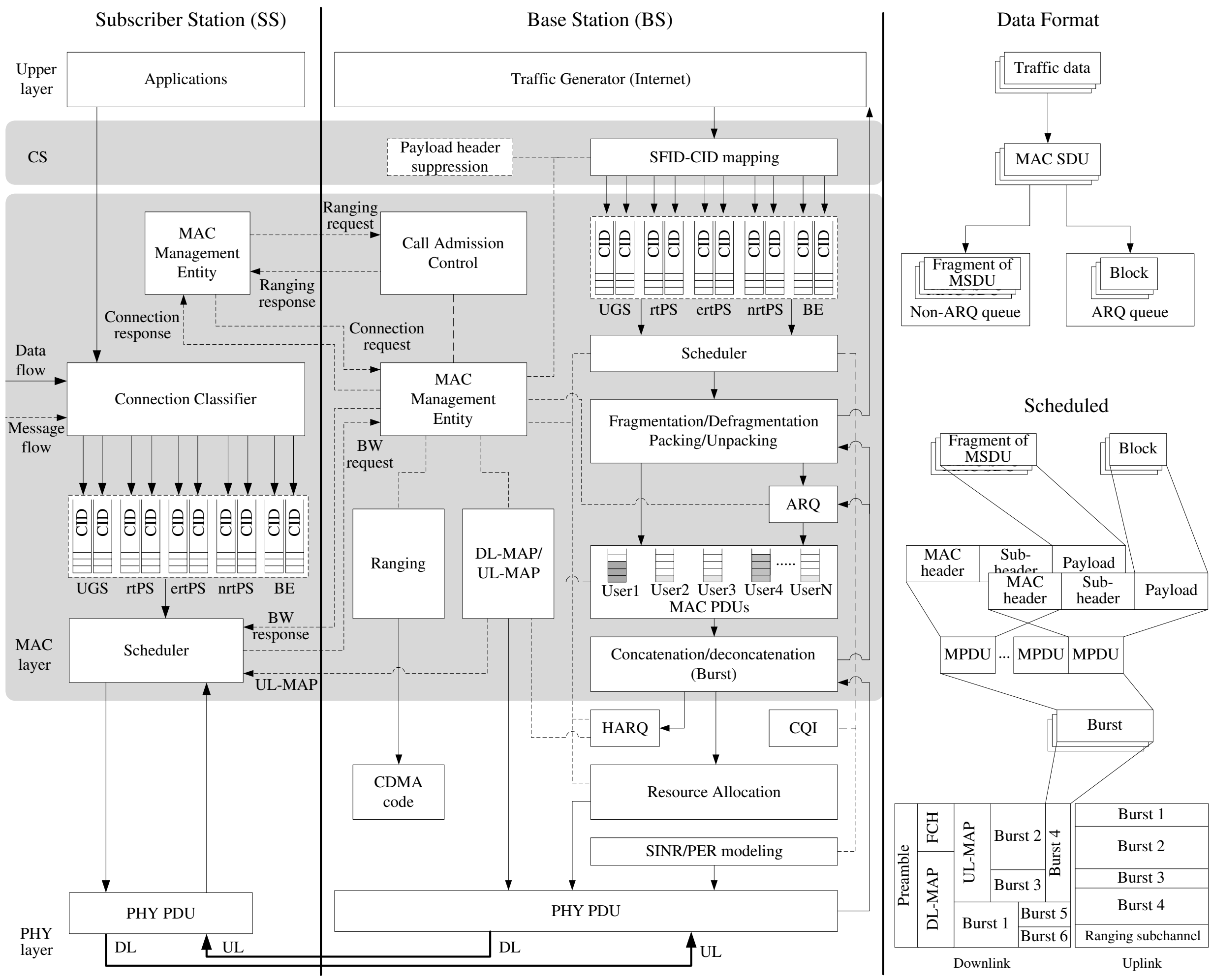

Figure 1: The MAC simulation architecture of IEEE 802.16.

does not define the admission control process. All packets from the application layer are classified by the connection classifier based on the CID and are forwarded to the appropriate queue. At the SS, the scheduler will retrieve the packets from the queues and transmit them to the network in the appropriate time slots as defined by the UL-MAP sent by the BS. The UL-MAP is determined by the scheduler module based on the BW-request messages. These messages report the current queue size of each connection in SS.

3. THE IEEE 802.16 NS-2 MODULE

The developed 802.16-based WiMAX module named as the `Mac802_16` class is in accordance with the specifications of the IEEE 802.16-2004 standard [1] and based on the ns-2 version 2.29 [11]. All modules are designed by using object-oriented programming language C++ and modeled as several classes. The relationship between the WiMAX module and legacy ns-2 modules is based on the original network component stack of the ns-2 as shown in Fig 2. It illustrates the type of objects for the traffic generating agent (TGA), the link layer (LL), the interface queue (IFQ), the designed MAC layer (WiMAX module), and the PHY layer (Channel).

First, the TGA is considered simply as an application level traffic generator that generates VoIP, MPEG, FTP, HTTP traffic, and so on. These traffic are classified into five different types of service, the UGS, rtPS, ertPS, nrtPS, and BE, each with its own priority. All packets will be transferred to different types of priority queues according to their service types by using CS layer SFID-CID mapping mechanism. The data packets in these queues are treated as MSDUs and will be selected to pass into the WiMAX module in a round robin manner.

While the WiMAX module in the SS receives the MSDUs from the Queue object, the MAC management component will initiate the ranging process to enter the WiMAX system or to transmit the MSDUs according to the scheduled time obtained from UL-MAP. Once the process has been successfully finished in the MAC layer, the Network Interface will add a propagation delay and broadcast in the air interface. The Channel object we used is the WirelessPhy class.

The WiMAX module also receives packets from the air

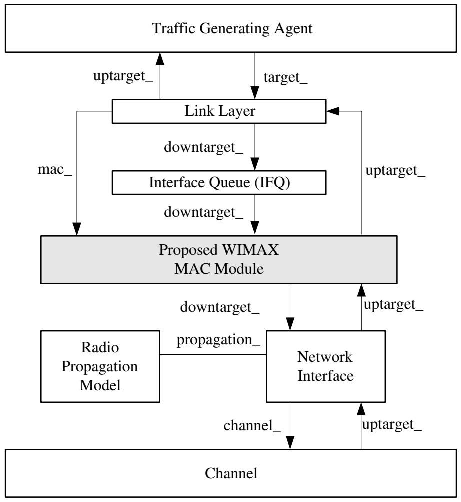

Figure 2: The relationship between the WiMAX module and legacy ns-2 modules.

interface passed from other nodes, and then it determines whether the packet is a control packet or not. If the packet is a control packet, the MAC management object will take corresponding procedures according to the control packet. If not, the packet will be passed to LL object after the defragmentation process. Finally, the TGA will receive the packets from the LL object.

The proposed WiMAX module is composed of the CS sublayer, the MAC CPS sublayer, and the PHY layer. All classes of components are depicted in Fig. 3, which graphically shows these objects, attributes, and their relationships. The BS and SS are identified as its corresponding numbers, which are determined in the OTcl object. The detail components of the WiMAX module are described as the following.

3.1 The CS Sublayer

The CS sublayer has two major functions: 1) transforming the IP address (from the upper layer) into several SFIDs or the reverse transformation (from SFID to IP address), 2) recording the mapping between a SFID and a transport CID (TCID). These functions enable the MAC layer to keep the essential information of the upper layer SDUs about their QoS parameters and destination addresses. We notice that the PHS function is not implemented in the WiMAX module since it is optional in the standard and is not related to the operations of the protocol.

3.1.1 IP-SFID mapping

The SDUs, which come from the upper layers, will contain the corresponding destination addresses and service types. An IP-SFID mapping function should record and classify the characteristics of the requesting packets for future IP-MAC mapping. A SFID is used for either the DL transmission with QoS parameters reference or the UL transmission with IP lookup.

3.1.2 SFID-TCID mapping

The SFID-TCID mapping is a main function of the CS sublayer for SFID to TCID mapping, which defines the QoS class of the service flow associated with the connection. For the UL traffic, the SS will send a bandwidth request header with the primary CID to the BS for data transmission by invoking the `BandwidthRequest()` function if it does not obtain a TCID. The SS can add, change, or delete its obtained bandwidth via bandwidth management messages: dynamic service addition, change, and deletion (DSA, DSC, and DSD) later. For the DL traffic (from Internet), the `insert_SFID()` function (in the BS) will determine whether the SS obtained a TCID. If not, this function will generate an unused TCID for the SS or transfer the MSDU into the corresponding QoS queue.

Since the connection of the WiMAX is bi-direction and each direction has at least five priorities (UGS, rtPS, ertPS, nrtPS, and BE), a SS may use all services (ten SFIDs including five for UL and five for DL) during its usage time. Therefore, for the reason of efficiency, in our designed WiMAX module, the BS will assign a default value of ten SFIDs to the SS a time as it first sends a bandwidth request to the BS, and associate a SFID with a TCID (assigned by the BS). We notice that the number of SFIDs assignment strategy may vary depending on different manufacturers.

The length of the SFID and TCID are 32-bit and 16-bit ($2m$+1–0xFEFE) long, where m is a variable depending on the setting of the operator, respectively. After the mapping operation, the SFID-TCID mapping will be recorded in both sides of the BS and the SS. Moreover, the SS also records the provided QoS service flow in the ProvisionQoSParamSet, the usage of QoS service flow in the AdmittedQoSParamSet, and the active QoS service flow in the ActiveQoSParamSet.

3.2 The MAC Sublayer

The MAC CPS sublayer is the main part of the MAC and maintains the MAC operations and management messages of the system. The management messages such as DCD, UCD, DL-MAP, UL-MAP, DSA, DSC, DSD, RNG-REQ, RNG-RSP, and so forth are generated in this sublayer. The concept of CPS architecture design follows the block diagram shown in Fig. 1. The main body of the MAC CPS is constructed by a `Mac802_16` class, which contains several independent functions such as `Ranging()`, `Fragmentation()`, `BandwidthRequest()`, and so forth. The detailed functions are described as follows.

3.2.1 Ranging

The initial ranging process is the first step in our module for a SS to enter the network. First, a new SS has to scan for the DL channel and establish synchronization with the BS. After synchronizing with the BS, the SS will obtain transmit parameters from the UCD message, which is periodically generated by the BS, to recognize the channel information for transmission. While an unregistered SS receives a packet from the Queue object, it will start the ranging process to notice the BS when entering the system. The SS sends the RNG-REQ management message in the ranging interval which is defined in the UL-MAP issued from the BS with quadrature phase shift keying (QPSK) 1/2 coding rate modulation for contending the entry of the system.

The entering process follows the random backoff mechanism with an initial backoff countdown interval of $(0, \mathrm{CW}_{\min}-1)$ where the $\mathrm{CW}_{\min}$ is the minimum contention window size and is equal to 32. At ranging period, the backoff time is uniformly chosen in the range $(0, \mathrm{CW}_{\min} - 1)$. After each

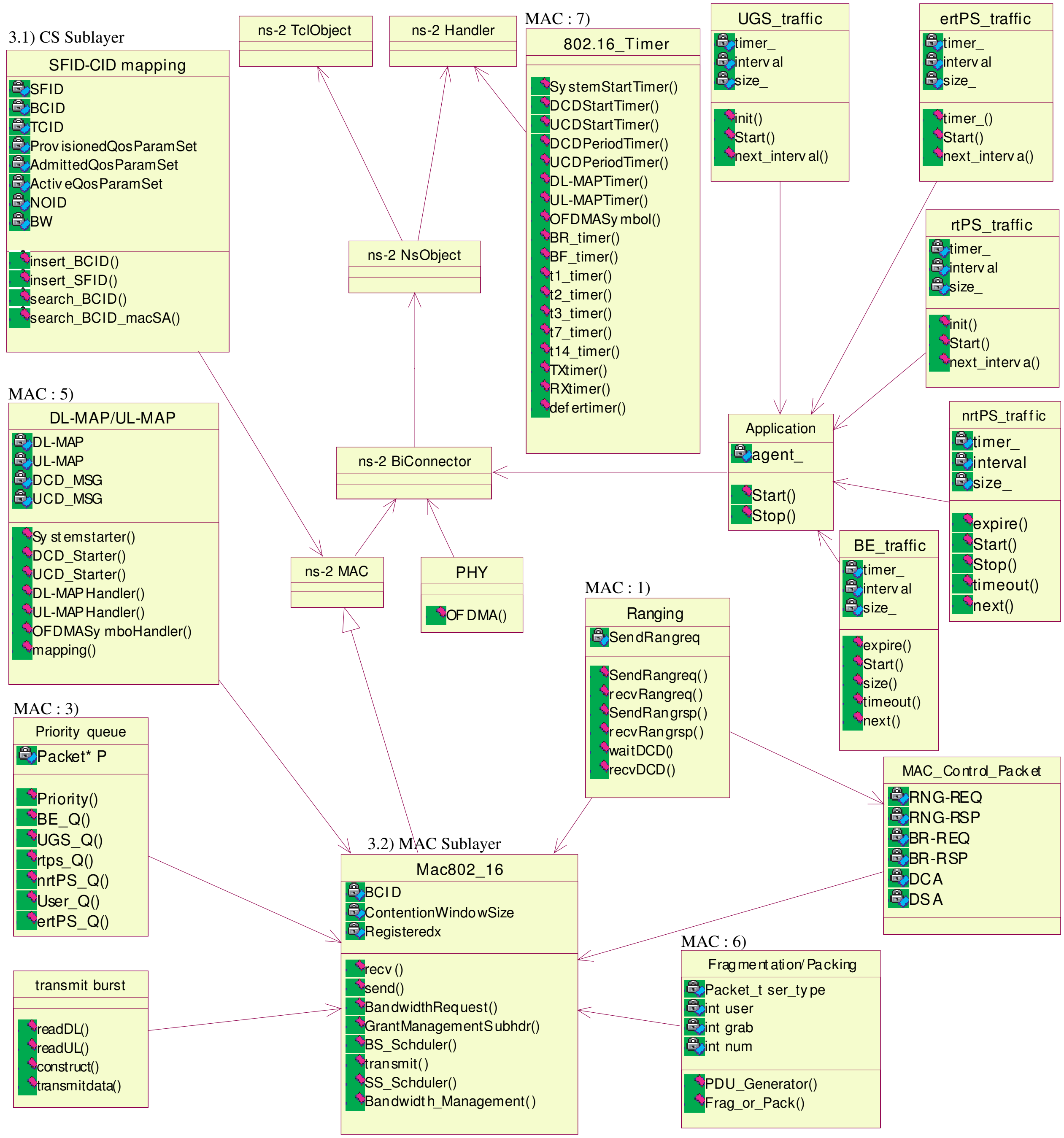

Figure 3: The class diagram of the designed WiMAX module.

unsuccessful transmission, the CW_{min} is doubled up to a maximum value $CW_{max} = 2^m CW_{min}$. The CW_{max} value is set to 1024 as defined in the standard. The SS uses CID value of zero to send RNG-REQ and starts a timer to wait for the RNG-RSP message from the BS. These processes are operated in two functions `rng_req()` and `rng_rsp()`.

If the SS receives the RNG-RSP before the timer expiration, the ranging process is successful. Otherwise, the SS will select a new backoff window size for a new ranging process. The collision detection of the RNG-REQ is set by the receiver timer. If more than one RNG-REQ message is sent within the time interval, these RNG-REQs are treated as collision. Otherwise, this message is successful. When the BS receives a RNG-REQ message from the SS, it will decide to let the SS join the networks or not. After determination, the BS will reply a RNG-RSP message following the DL-

MAP among the next several superframes. The RNG-RSP contains an unique basic CID and a primary CID to the SS for future communications.

3.2.2 MAC management

Five kinds of messages, DCD, UCD, DL-MAP, UL-MAP, and bandwidth request (BR), are used in this function. Each message has its own management message type and they can be discriminated by each other. The DCD includes the management message type, downlink channel ID, TLV encoding information for the overall channel, and the downlink burst profile. The DCD channel encoding is composed of the TLV specific, which includes all the channel information, such as the DL burst profile (may appear more than once), the frame duration, PHY type, power adjustment rule, channel number, the transmit/receive transition gap (TTG) and the receive/transmit transition gap (RTG), the frequency of the downlink center frequency, the BSID, the frame duration code, and the frame number.

The important point of the DCD is the downlink burst profile, which includes the DIUC (in order to map to the DL-MAP) and the TLV encoded information. In the TLV encoded information DCD burst profile, there are FEC code type, DIUC mandatory exit threshold, as well as the DIUC minimum entry threshold. The FEC code type can indicate the modulation type of the burst. The DIUC mandatory exit threshold will define the range of the CINR and indicate the DIUC that can no longer be used, and where this change to a more robust DIUC is required. Similarly, the DIUC minimum entry threshold is the minimum requirement for CINR in order to start using this DIUC.

The UCD includes management message type, ranging backoff start, ranging backoff end, request backoff start, request backoff end, and the TLV encoding information for the overall channel. The significance of UCD is the TLV encoding information for the overall channel. It constructs the uplink burst profile. Same as the downlink burst profile, the uplink burst profile also contains the FEC code type and modulation type. The ranging data ratio is also included in the uplink burst profile, which means the reducing factor between the power used for this burst and power used for CDMA ranging. The last TLV encoding information in uplink burst profile is the normalized C/N override. This is a list of numbers, where each number is encoded by one nibble and interpreted as a signed integer. All of the MAC messages mentioned above are triggered by specific timers.

First, all traffic flows are generated by the traffic generating agent as shown in Fig. 2. These data flows will be treated as the basic packet object defined in the ns-2. Then these packets will come to the `Mac802_16` through the *interface queue* (IFQ) and be treated as the MSDUs. Once the MSDU comes, the `insert_SFID()` is invoked in order to classify the MSDUs into several groups, such as UGS, rtPS, ertPS, nrtPS, and BE. If the SFID is set as active, then the MSDU will be transferred into the queue labeled as a TCID number; otherwise, the `insert_SFID()` will assign a TCID and set the corresponding SFID as active.

After the service flow classification, these MSDUs will be transferred into their corresponding queue and be held to be served. In this stage, either it is in the DL or the UL channel, the BS has to manage the bandwidth by invoking the bandwidth management function `Bandwidth_Management()`, which plays the call admission control (CAC) mechanism of each SS in the UL and the DL bandwidth management. In the implementation of the module, the CAC mechanism follows the first-in-first-served (FIFS) basis to admit the coming requests. If the bandwidth is enough for serving the request, this request will be allowed to enter the system; otherwise, it will be denied by CAC immediately.

The SS may request to perform bandwidth request with BS by using `BandwidthRequest()` and the related parameters, e.g., CID, type, encryption control (EC), and header type (HT), and so on. The HT field of the MAC header is set to one for indication of a BR. The SS will calculate its required bandwidth and set the BR field (19 bits) to a corresponding bandwidth (1–524287 bytes). Afterward the SS will continue to observe the upcoming UL-MAPs to check whether its request is successful or not. The bandwidth request process follows the random backoff approach as described in ranging process. Once the requested bandwidth is admitted by the BS, the SS can invoke `GrantManagementSubhdr()` for future grant management if SS needs more bandwidth. The `GrantManagementSubhdr()` will generate a subheader for an indication of piggyback request, poll-me, or slip indicator of the active TCID.

3.2.3 Priority queue

In the BS or SS, the packets that come from the upper layer will be prior delivered to `Priority()`. According to the TCID and its service type: UGS(5), rtPS(4), ertPS(3), nrtPS(2), BE(1), the `Priority()` will make a corresponding priority classification. The `Priority()` generates an exclusive queue to store these packets based on its TCID. Finally, packets will be treated as MSDUs and be segmented by different queue function, e.g. `UGS_Q()`, `rtPS_Q()`, and `BE_Q()`, etc. Notice that different TCIDs will refer to a same classification if their service types are same, namely, a classification may contains several queues with unique TCIDs at the same time.

3.2.4 Scheduler

The `Scheduler()` function is in charge of selecting queued MSDUs according to the admitted bandwidth. The selection police of the scheduler in the designed module uses the weighted Round-Robin method. To begin with, in the DL, we associate one percentage parameter with each classification as $q5, q4, q3, q2, q1$, which is corresponding to the UGS, rtPS, ertPS, nrtPS, and BE, respectively. In the first round, the expected serving quantity of each classification is calculated as $B^T_{\text{type}} = \min(R_{\text{type}}, B_{\text{total}} * qi), i \in \{1, \ldots, 5\}$ and $\sum_{i=1}^{5} qi \le 1$, where R_{type} represents the total amount of requested type services and B_{total} represents the total available bandwidth of the system. The parameters $\{q5, q4, q3, q2, q1\}$ are variables and can be regulated by any simulation need.

In the second round, the `Scheduler()` will serve the remaining, unserved services in priority order. If all remaining services in priority i are served, the `Scheduler()` will serve the next priority $i + 1$ and so on. This process will be repeated until whole available bandwidth are exhausted or remaining required services are served. The adopted strategy is used to guarantee that lower priority traffic can still obtain a minimum bandwidth for transmission if the traffic load is extremely heavy. We emphasize that the scheduling algorithm or police is not mandatory in the standard specifications. In other words, this implies that researchers or engineers can design their own `Scheduler()` function according to their specific purposes or usages to substitute for this one. In addition, the ARQ function is an optional subject matter and is not implemented in our module.

3.2.5 DL-MAP/UL-MAP

The DL-MAP and UL-MAP are periodically generated to announce the information of the arrangement of the DL and UL periods in the superframe. These two messages are handled by `DLmapHandler()` and `ULmapHandler()`. There are management message types, PHY synchronization field, DCD count, base station ID, and DL-MAP_IEs (IE: information element) in the DL-MAP message. The important part in the DL-MAP are the DL-MAP_IE()s, which are composed by the type-length-value (TLV) encoding. Each DL-MAP_IE is generated by `DL_MAP_IE()` and each DL-MAP_IE contains the downlink interval usage code (DIUC), the CID, the number of CIDs assigned for this IE, the OFDMA symbol and subchannel offset, the number of the OFDMA symbols, and the number of the subchannels.

The structure of UL-MAP is similar to the DL-MAP, but the differences between them are the uplink channel ID and the allocation start time. The uplink channel ID is the identifier of the uplink channel to which this message refers. The allocation start time is the effective start time of the uplink allocation defined by the UL-MAP. The UL-MAP_IE structure is also similar to the DL-MAP_IE. The capability of the DL-MAP and the UL-MAP will decide the time domain and the frequency domain in the frame space.

3.2.6 Fragmentation/Packing

The packet fragmentation or packing process is executed by `PDU_Generator()` function. This function grabs the MSDUs from QoS queues (UGS, rtPS, ertPS, nrtPS, and BE) and produces MPDUs depending on the command of the `Scheduler()`. It will generate the generic MAC header for each data payload. Fragmentation is the process that divides a MSDU into one or more MPDUs. If packing is turned on for a connection, the MAC may pack multiple MSDUs into a single MPDU. In this module, the input MSDU will be fragmented or packed depending on the length of the MPDU. Due to the reason of simplicity, we set the length of each MPDU fixed. Once the fragmentation or packing process is proceeded, the corresponding subheader will also be given to each MSDU contained in a MPDU.

After data fragmentation and packing, the scheduler will invoke `Transmit_Data()` for data transmission. The treatment of the transmission will be various depending on whether it happened in the SS or BS. In the SS, the scheduler concatenates the MPDUs into one burst transmission according to the arrangement of the UL-MAP. In contrast to SS, the BS concatenates the MPDUs into one burst transmission according to the DL-MAP, which is generated by the scheduler. This function is periodically triggered in each superframe to decide to transmit burst data to/from DL or UL of the BS or SSs.

The `Assembler()` function is a process function of defragmenting and unpacking received data burst. It will read the MAC header to see whether this MPDU is fragmented or packed. Furthermore, the subheaders information such as FC in MPDU will also be read to recover an original MSDU.

3.2.7 802.16 timer class

The 802.16 `Timer` class inherits the `Handler` class with three important functions:

- The `start()` is used to trigger the timer to start.
- The `stop()` is used to stop the timer if the event happened before expiration.
- The `handle()` is used to trigger event while time runs out.

These `Timer` classes play an important role of the system such as sequencing the events between the BS and SSs in WiMAX networks. For instance, each superframe starts from the `DL-MAPTimer` and then it triggers the following timers, `UL-MAPTimer`, `DCDPeriodTimer`, and `UCDPeriodTimer` iteratively. Another kind of timer is used to count down the given specific time before the expected time expires or an event is encountered, e.g., the SS starts a RNG-REQ timer to wait for the RNG-RSP from the BS. All timer intervals defined in the WiMAX module are referred to the IEEE 802.16 standard.

4. SIMULATION PARAMETERS AND DEMONSTRATIONS

Table 1: Parameters Used in the MAC and Physical Layers

Parameters	Value
MAC Layer Parameter	
DL/UL ratio	3:2
No. of OFDMA symbol per frame	49
No. of OFDMA symbol per frame	48 (data portion)
No. of subchannels	30
CW_{min}	32 opps
CW_{max}	1024 opps
Ranging opp. per Frame	12 OFDMA symbols
Max. no. of ranging retry	10
Bandwidth request opp. per frame	12 OFDMA symbols
Max. no. of bandwidth req. retry	10
Initial ranging CID	0
Basic CIDs	1–1000
Primary CIDs	1001–2000
Transport/secondary Mgt. CIDs	2001–65278
Broadcast CID	65535
SFID range	1–4294967295
Physical Layer Parameter	
Spectrum	5.0 GHz
Bandwidth	20 MHz
QPSK 1/2	4.99 Mbps
QPSK 3/4	7.48 Mbps
16-QAM 1/2	9.97 Mbps
16-QAM 3/4	14.96 Mbps
64-QAM 2/3	19.95 Mbps
64-QAM 3/4	22.44 Mbps
QPSK 1/2	-79 dBm
QPSK 3/4	-76 dBm
16-QAM 1/2	-72 dBm
16-QAM 3/4	-69 dBm
64-QAM 2/3	-65 dBm
64-QAM 3/4	-63 dBm

The system-specific parameters of the IEEE 802.16 MAC protocol we used are shown in Table 1 and Table 2 respectively. The simulation environment, shown in Fig. 4, is set one serving BS to 10 SSs concurrently within a 1000m×1000m square. All SSs are randomly developed around the BS and

Table 2: System Time Parameter

Parameter	Value
OFDMA symbol time	100.84 μs
OFDMA frame length	5 ms
DCD/UCD period	10 sec
Ranging interval	1210.08 μs
Bandwidth request interval	1210.08 μs
TTG	200 μs
RTG	200 μs
T1–T26	as defined in IEEE 802.16

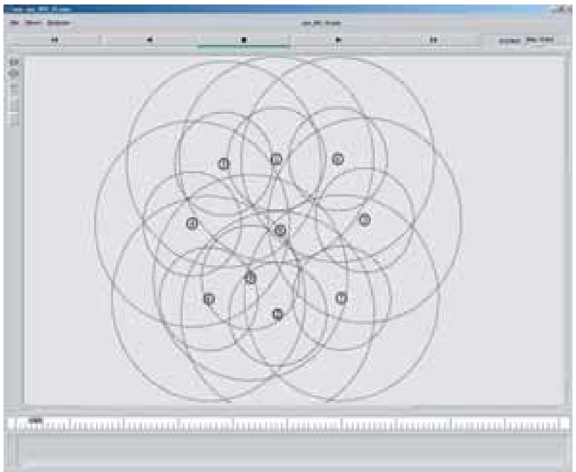

Figure 4: A snapshot of the simulation topology.

the modulation versus distance model is based on [4], i.e. the achievable transmission rate depends on how far the distance between the BS and SS is. All SSs execute the ranging request process by adopting QPSK 1/2 encoding rate.

There are three kinds of service flows: UGS, nrtPS, and BE which are all generated from the traffic generating agent in both the SSs and the BS. The Internet traffic is treated as the DL traffic to the SSs; on the contrary, the UL traffic is the traffic from the SSs to the Internet. For CBR traffic, there are fourteen UGS connections (seven for DL and seven for UL) and each connection occupies a fixed 1024 kbps data traffic. For VBR traffic, there are a total of four nrtPS connections (two for DL and two for UL) and each connection occupies a mean data arrival rate 448 kbps and the data length follows the uniform distribution model by setting `Uniform(200,980)` (between 200 bytes–980 bytes) and time interval `Uniform(-0.5,0.5)`, i.e. each connection occupies about an 1.5 Mbps. The traffic model of BE is same as VBR traffic model but the numbers of connections are one for DL and one for UL and the data length is between 512 bytes–1024 bytes. The priority order of the traffic are UGS, nrtPS, and BE, and are scheduled in the weighted Round-Robin manner.

Fig. 5 shows the throughput as a function of simulated time. The simulation time persists for 50 seconds. All traffic data are continuously generated throughout the simulation time. We can see that the curve of the obtained throughput of the system raises with the increasing of the simulation time. The reason why the system throughput is low in the early simulation time is that SSs spend an amount of time

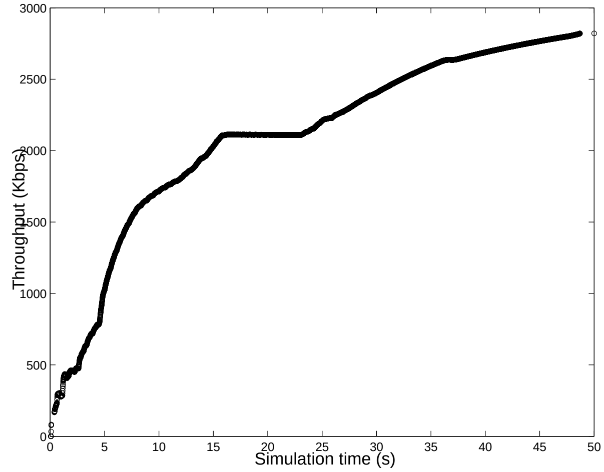

Figure 5: The system throughput versus simulation time in 50 seconds.

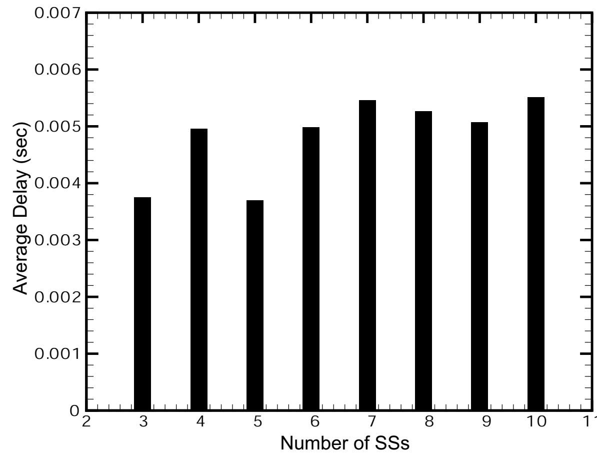

Figure 6: The average access delay versus different number of SSs through the simulation time.

in dealing with the initial ranging process and their bandwidth request process. It will then follow the random backoff mechanism with an initial backoff countdown interval and stand on the random backoff approach. Therefore, the system throughput is not revealed well. Finally, we can see that the system throughput will reach around 2.8 Mbps in the end of the simulation time.

Fig. 6 illustrates the average MAC delay under given number of SSs in detail. We can see that the delay time will increase with the growth in number of SSs. The MAC delay is a result from the collision of initial ranging and the bandwidth request. After the bandwidth request, the delay will become be balanced since the BS will arrange the transmission time in the simulation. The scheduling of different traffic service types will mainly affect the MAC delay because of limited spectral resource. Using the weighted Round-Robin to access the priority queues is not a better way to schedule the transmission and it can be replaced to a better scheduler in the future work.

5. CONCLUSIONS

The paper presents a detailed design and implementation of the WiMAX simulation module for ns-2. The designed module is based on the IEEE 802.16-2004 standard and the legacy ns-2 version 2.29. The unified modeling language (UML) is also adopted to design and analyze the WiMAX module. This module includes a basic point-to-multipoint (PMP) IEEE 802.16 function, a different service flows generator, a simple bandwidth management component, and the scheduler. We have also demonstrated a simulation scenario to verify the designed module. We hope that this preliminary WiMAX module can benefit academic researchers and industrial developers for early verification of designing the WiMAX system.

Future work will focus on providing mobility functions [3] of the SS and the relay station (RS) which is under defined in the IEEE 802.16j standard. In addition, an efficient bandwidth management algorithm and scheduler algorithm for QoS control are crucial for performance enhancement of the WiMAX system. These two functions are also expected to be enhanced further.

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