Mobile WiMAX Network Planning and Optimization

S. O. Ajose and O. L. Erhuen

***Abstract*—Software suitable for estimating Mobile WiMAX capacity in network planning and optimization is presented. The implementation of the software is based on analytical method to evaluate IEEE 802.16e Mobile WiMAX system's capacity, throughput and a traffic model for mixed application users. Various Overheads that impact the capacity of the system are analyzed. A step by step description of the analysis is made and a flow chart for the determination of available bandwidth and maximum number of users supported is presented. Based on the description of the flow chart, a program in java language that implemented the entire analysis is written. A simulation of the software is used for the determination of the maximum number of subscribers that each specific Mobile WiMAX sector can support. This would help service providers to plan and implement a wide coverage network in a city. The proposed analytical method and software program will enable service providers to estimate the number of base stations that can be deployed in a given area. Thus the network investment, profitability and avoidance of future network congestion can be evaluated and estimated.**

***Index Terms*—IEEE 802.16e, mobile WiMAX, overheads.**

I. Introduction

IEEE 802.16e Mobile WiMAX is the standard for broadband wireless access (BWA) in a metropolitan area. It provides high speed, high quality wireless internet data rate on longer distances to large geographical areas. It has a maximum transfer speed of 70 Mbps per channel and a maximum range of 50km for fixed station and 5 – 15Km for mobile stations. The Mobile WiMAX system adopts orthogonal frequency Division Multiple Access (OFDMA) which is a multiplexing technique that subdivides the bandwidth into multiple frequency sub-carriers for improved multi path performance in non line of sight environment. OFDMA sub-channelization technique used by WiMAX provides high scalability and support to a number of application including voice, data, video streaming. Frequency reuse factor, smart antenna technique, mobility and power management make WiMAX more powerful to provide high throughput and larger coverage [1], [2].

Due to the promising nature of Mobile WiMAX, many service providers have been deploying Mobile WiMAX equipment and infrastructure. For service providers who plan wide coverage network in a city, determination of the maximum number of subscribers that can be supported with their various applications is of paramount interest to them. Also, the number of base stations that can be deployed in a given area to bring about the right quality of service and quality of experience is important for proper planning and optimization [2].

An analytical method of capacity estimation and a simulation to evaluate the maximum number of subscribers a Mobile WiMAX BS can support is presented. This was done by writing a software programme in Java that provides analytical data necessary for network capacity planning and optimization. The input parameters to the software can be changed and effect of the changes observed to allow for proper analysis. Thus the network investment, profitability and avoidance of future network congestion can be evaluated and estimated.

II. Mobile WIMAX PHY Layer Overview

WiMAX physical layer is based on orthogonal frequency division multiplexing (OFDM). OFDM is the transmission scheme of choice to enable high-speed data communication in broadband system. OFDM based on the idea of dividing a given high-bit rate data stream into several parallel lower bitrate stream and modulating each stream on separate subcarrier [1].

For performance modeling of Mobile WiMAX, it is important to have an understanding of Orthogonal Frequency Division Multiple Access (OFDMA). Presently OFDMA has been fully adopted and implemented by Mobile WiMAX technology and upcoming broadband access technology. Mobile WiMAX technology has been designed to be able to scale to work in different channelization from 1.25 to 28MHz to comply with varied worldwide requirement as efforts proceed to achieve spectrum harmonization in the larger term [2].

The channel is divided into many equally spaced subcarriers. There are four different types of sub-carrier in an OFDMA symbol. Data sub carrier (used for data transmission), Pilot sub-carrier (reserved for monitoring the quality of the channel), guard sub-carrier (for providing safety zone between channel) and DC sub-carrier (for use as reference frequency) [3].

For example, a 10MHz channel is divided into 1024 subcarriers forming 35 uplink (UL) sub channels. A sub-channel is the minimum transmission unit in an OFDMA frequency dimension. In the downlink, a slot consists of 2 clusters where each cluster consists of 14 subcarriers over 2 symbol times. It is the minimum possible data allocation unit in the 802.16 standard, having both time and sub-channel dimension. Thus the downlink sector is made up of 28 groups of subcarriers called a sub-channel resulting in 30 DL sub-channels from 1024 sub-carriers at 10 MHz [4].

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A. WiMAX OFDMA Frame Structure

Mobile WiMAX profiles use not only Frequency Division Duplexing but also Time Division Duplexing in which the DL and UL share the same frequency but alternate in time. The transmission consists of frames. The DL subframe and UL subframe are separated by a TTG (Transmit-to-Transmit Gap) and RTG (Receive to Transmit Gap). The frames are shown in two dimensions with frequency along the vertical axis and time along the horizontal axis [4].

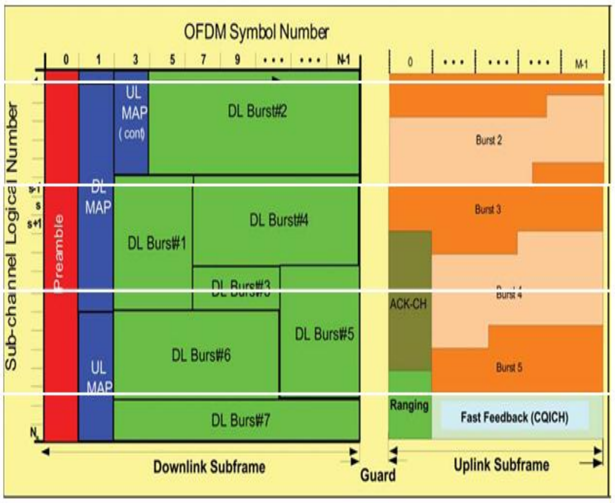

Fig. 1. WIMAX OFDMA frame structure [4].

The WiMAX DL subframe as shown in Fig. 1 starts with one symbol column of preamble. Other than preamble, all other transmissions use slots. The first field in DL subframe after the preamble is a 24-bit Frame Control Header (FCH). For high reliability, FCH is transmitted with the most robust Modulation Code Scheme (MCS) (QPSK 1/2) and is repeated 4 times. Next field is DL-MAP which specifies the burst profile of all user bursts in the DL subframe. DL-MAP has a fixed part which is always transmitted and a variable part which depends upon the number of bursts in DL subframe. This is followed by UL-MAP which specifies the burst profile for all bursts in the UL subframe. It also consists of a fixed part and a variable part. Both DL MAP and UL MAP are transmitted using QPSK 1/2 MCS [4].

B. Mobile WIMAX MAC Layer Description and QoS Support

The MAC layer is based on the time-proven DOCSIS (Data Over Cable Service Interface Specification) standard and can support bursty data traffic with high peak rate demand while simultaneously supporting streaming video and latency-sensitive voice traffic over the same channel [2]. The MAC layer is formed with three sublayers:

- Service specific convergence sublayer (CS)
- Privacy sublayer and
- MAC common part sublayer (CPS)

The MAC CS receives higher level data through CS Service Access Point (SAP) and provides transformation and mapping into MAC Service Data Unit (SDU).

The Privacy sublayer lies between the MAC CPS and the PHY layer. Since security is a major issue for public networks, this sublayer provides the mechanism for encryption and decryption of data transferring to and from PHY layer and is also used for authentication and secure key exchange. Data, PHY control, statistics are transferred between the MAC CPS and the PHY through the PHY SAP

The MAC CPS is the core part of the MAC layer, defining medium access method. The CPS provides functions related to duplexing and channelization, channel access, PDU framing, network entry and initialization [5]. This provides the rules and mechanism for system access, bandwidth allocation and connection maintenance. The common part sublayer defines five quality of service classes as shown in Table I.

TABLE I: MOBILE WIMAX APPLICATIONS AND QUALITY OF SERVICE CLASSES [4]

QOS Classes	Applications	QOS Specification
UGS Unsolicited Grant Service	VoIP	• Maximum Sustained Rate • Maximum Latency Tolerance • Jitter Tolerance
rtPS Real-Time Polling Service	Streaming Audio or Video	• Minimum Reserved Rate • Maximum Sustained Rate • Maximum Latency Tolerance • Traffic Priority
ErtPS Extended Real-Time polling Servive	Voice With Activity Detection (VoIP)	• Minimum Reserved Rate • Maximum Sustained Rate • Maximum Latency Tolerance • Jitter Tolerance • Traffic Priority
nrtPS Non Real-Time Polling Service	File Transfer Protocol (FTP)	• Minimum Reserved Rate • Maximum Sustained Rate • Traffic Priority
BE Best-Effort Service	Data Transfer, Web Browsing, etc	• Maximum Sustained Rate • Traffic Priority

C. Quality of Service (QoS) Support

A key concept in QoS is Service Flow. Each service flow or category is associated with a unique set of QoS parameters, such as latency, jitter throughput, and packet error rate, that the system strives to offer. Table I illustrates service flows supported in Mobile WiMAX and gives example applications for each. Before providing a certain type of data service, the BS's MAC establishes a unidirectional connection with its peer MAC layer in the user terminal to discuss the agreed service flow and assign the QoS parameters over the air interface.

The efficiency of resource allocation (time and frequency) in both DL and UL is controlled by the scheduler that is located in each BS. The scheduler controls the traffic trend by monitoring CQICH (Channel Quality Indicator) feedback to provide the best resource allocation that supports the QoS parameters for each connection. The scheduling process is done on a frame by frame base in response to traffic and channel conditions [6]-[8].

More information on Mobile WiMAX MAC and PHY layer overview are available in numerous texts on WiMAX network [9]-[11].

III. CAPACITY EVALUATION ANALYSIS

For efficient planning and optimization of Mobile

WiMAX network, the number of connections that the wireless channel can support while providing the right QoS and experience without unduly degrading the system must be known.

In evaluating the capacity of a Mobile WiMAX network, the amount of signal overhead must be taken into consideration. This signal overhead is not constant but changes with the number of users. In other words, as the subscribers may have different capabilities in their supporting technologies the needed signaling procedure is different from one subscriber to the other in both DL and UL. In addition, since the system supports different QoS specifications, different service provision methodologies are used in resource allocations and scheduling processes on a subscriber based manner [12]. Therefore, the capacity available for data transmission is affected by the overhead due to the control message whose size in turn depends on several factors including the number of subscriber stations that are scheduled in a frame.

In calculating the actual throughput, the above conditions were put into consideration in our analysis and some basic assumptions made in the capacity evaluation are presented.

A. *Modulation Distribution Assumption*

The modulation distribution of the area under cover must be available in order to effectively analyse the capacity of a base station. According to the IEEE-802.16e-2000 standard, support for QPSK, 16QAM and 64QAM are mandatory in the DL with Mobile WiMAX. In the UL, 64QAM is optional. Both Convolutional Code (CC) and Convolutional Turbo Code (CTC) with variable code rate and repetition coding are supported as shown in Table II.

TABLE II: MODULATION AND CODING SUPPORTED IN MOBILE WIMAX

	DL	UL
Modulation	QPSK, 16QAM, 64QAM	QPSK, 16QAM, 64QAM
CC	½, 2/3, ¾,5/6	½, 2/3, 5/6
CTC	½, 2/3, ¾,5/6	½, 2/3, 5/6
Repetition	X2, x4, x6	X2, x4, x6

TABLE III: MODULATION DISTRIBUTION ASSUMPTION

Modulation Type	Coding Rate	Weight	Number of bits/symbol (K)
BPSK	½	5.0%	1
QPSK	½	2.5%	2
	¾	2.5%	2
16-QAM	½	5.0%	4
	¾	5.0%	4
16-QAM	2/3	40.0%	6
	¾	40.0%	6

The raw bandwidth of the DL channel is given by [7]:

$$BW_{raw} = \frac{FFT_{used} \times \sum(\%P\ k\ OCR)}{T_S} \quad (1)$$

where,

FFTused is the number of data subcarriers that is dependent on the channel bandwidth, the direction and its permutation scheme, *%P* is the percentage (weight), *k* is the number of bits per symbol, *OCR* is the overall coding rate and *Ts* is OFDMA symbol time.

Note that the quantity of FFTused in each direction depends on the permutation mode. The mandatory permutation mode in Mobile-WiMAX standard is the Partially Used Subchannelization, PUSC.

In a Time Division Duplexing frame, TDD, the total available bandwidth is shared between DL and UL subframes. So in order to achieve the raw-bandwidth in each direction, partitioning must be considered. For example if the DL *BWraw* is to be calculated in a 5MHz channel width, in accordance with WiMAX standard, the *FFTused* value using PUSC is 360 and should be considered in (1), while the result should be multiplied by ((DL+UL)/DL) ratio. On the other hand, for UL BWraw, *FFTused* should be 272 for 5MHz PUSC, while the result of the equation must be multiplied to ((DL+UL)/UL) ratio where values of DL, UL should be in ratio 1:4 [8].

B. *Application Distribution and Parameters*

Estimation of the number of users that each BS may support is essential in network planning. To have an idea about the maximum number of subscribers that a typical BS can serve, then information of possible different traffic types and their parameters are important. The traffic engineering for how the bandwidth is apportioned to the various active connections is typically left to operator configuration and is not included in the WiMAX standard.

In this paper, different application classes of WiMAX and their parameters and usage percentage related to each of the applications are presented.

There are several applications that are defined based on IEEE-802.16e-2005 standard. The WiMAX Forum has broken these applications into five major classes as shown in Table IV.

TABLE IV: APPLICATION DISTRIBUTION ASSUMPTION [2]

APPLICATION	Data Rate (kbps)	Weight
Multiplayer interactive gaming	50	25%
VOIP and Video Conference	32	10%
Streaming Media	64	12.5%
Web Browsing	Nominal	32.5%
Media Content Downloading	Best Effort	20%

In dimensioning a WiMAX network, one needs to keep in mind the user traffic demand and the applications it uses so that the density of the Base Stations and backbone network dimensioning can fulfill the demand. In [8], two main subscribers' classes were assumed. These are Business and Residential Subscribers. Therefore in this paper, the traffic demand is categorized into these two subscriber classes (i.e Business and Residential). Using the values from Table IV, the traffic demand calculation path for residential and business class subscribers can be evaluated. Hence, the total traffic demand for DL sector can be estimated.

In practice, the traffic parameters in DL are more accessible and thus in our analysis the DL demand is considered.

IV. Bandwidth Estimation and Maximum Number of Subscriber Algorithm

To derive the capacity of a Mobile WiMAX BS, two major assumptions have been made. First, a model modulation distribution in order to obtain system's raw data rate was made. Secondly, application distribution and parameter assumption model for subscribers traffic demand was also made.

TABLE V: OFDMA Model Parameter for Mobile WIMAX [2], [4], [12]

Parameters	Values	
System bandwidth (MHz)	5	10
Sampling factor	28/25	
Sampling frequency (F_s, MHz)	5.6	11.2
Sample time ($1/F_s$, nsec)	178	89
FFT size (N_{FFT})	512	1024
Subcarrier spacing (Δf, kHz)	10.93	
Useful symbol time ($T_b = 1/\Delta f$, μs)	91.4	
Guard time ($T_g = T_b/8$, μs)	11.4	
OFDMA symbol time ($T_s = T_b + T_g$, μs)	102.8	
Cyclic Prefix	1/4,1/8,1/16,1/32	
Frame duration (T_f, msec)	5	
DL:UL ratio	3:1 – 1:1	

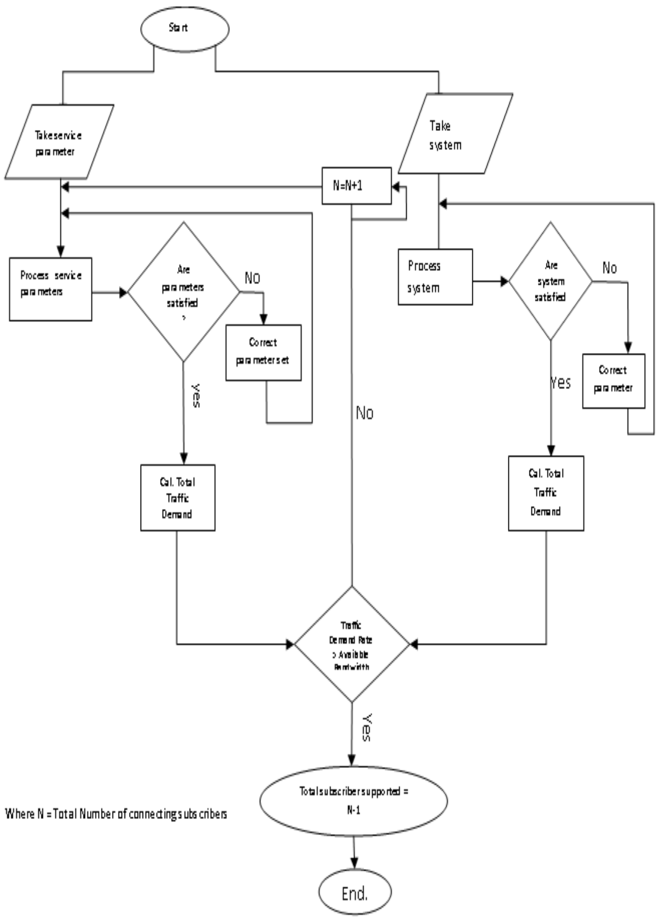

Fig. 2. Software development flow Chart [7].

Table V shows the model OFDMA parameters for raw capacity calculation and a review of the initial inputs parameters to our software development is next presented (see Fig. 2).

G value: That is the index to define the cyclic prefix duration to calculate the symbol time (*Ts*). Note that in Mobile WiMAX certification the useful symbol duration (*Tb*) is fixed at 91.4 µS for all possible bandwidths. Having the *FFTused* and *Ts*, based on the modulation distribution assumption, one can obtain channel's raw bandwidth.

DL:UL Ratio: This is used to obtain the Raw BW in each direction and also to calculate the duration of DL subframe (TDL) and UL duration (TUL). In calculating the duration of the DL subframe (TDL), the DL:UL ratio is multiplied by *Tf* (frame duration) which is equal to 5mS.

V. Simulation Results and Analysis

In Mobile WiMAX capacity calculation, lots of parameters are imputed and these parameters are used to calculate the number of subscribers supported by a base station. Some results obtained from our WiMAX capacity calculation include the minimum and maximum data rates, available data rates and so on. Three examples are simulated with our capacity software and the results are considered in the following case studies.

A. Case Study I

Using the following set of parameters in Tables VI and VII in our Mobile WiMAX capacity calculation software the maximum number of users supported by the base station was 76. The results obtained are shown in Fig. 3 and Fig. 4.

TABLE VI: OFDMA Service Class Parameters for Case Study 1

Subscribers Class	Data Rate	Percentage (%)	Contention Ratio	Over Subscription Ratio
Business Class	2000	40	10	50
Residential Class	512	60	30	50

TABLE VII: OFDMA System Class Parameters for Case Study 1

Channel Bandwidth	Subframe Ratio	Cyclic Prefix Rate	DL/UL Ratio	PDU's Per Data Burst	Connections per PDU
5	3/1	1/8	4	2	2

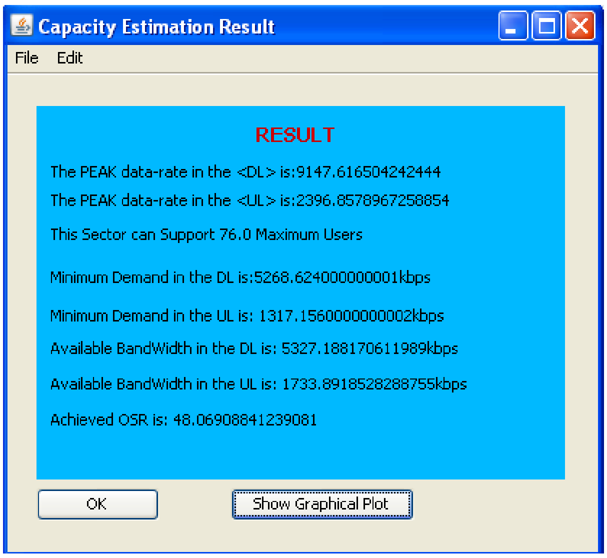

Fig. 3. Capacity result interface for case study I.

On calculation, the result according to Fig. 4 shows that the sector can support 76 mixed traffic users. Based on the modulation and application distribution assumptions and the traffic demand, the bandwidth demand of the 77th user can not be afforded in the DL direction.

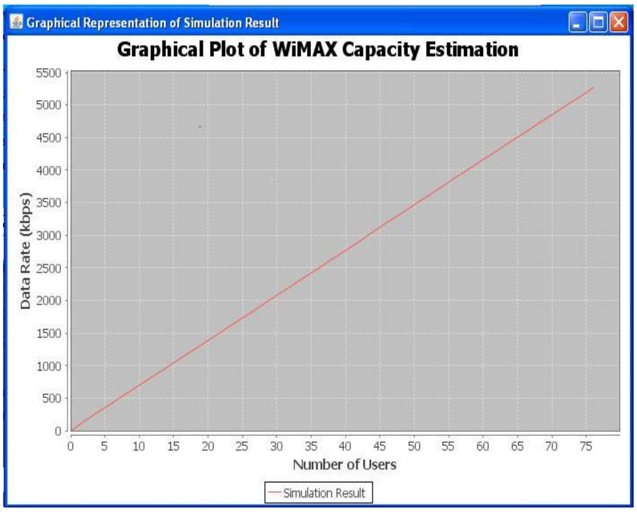

Fig. 4. Comparison of DL data rate to the number of subscribing users.

The minimum demanded data rate for 76 simultaneous users that can be fulfilled with the available bandwidth is approximately 5268.62 kbps. Fig. 5 shows the graphical representation of data rate result. From Fig. 5, the peak data rate in DL is approximately 9147.62 kbps which then decreases to 5327.19 kbps as the number of users reaches to 76.

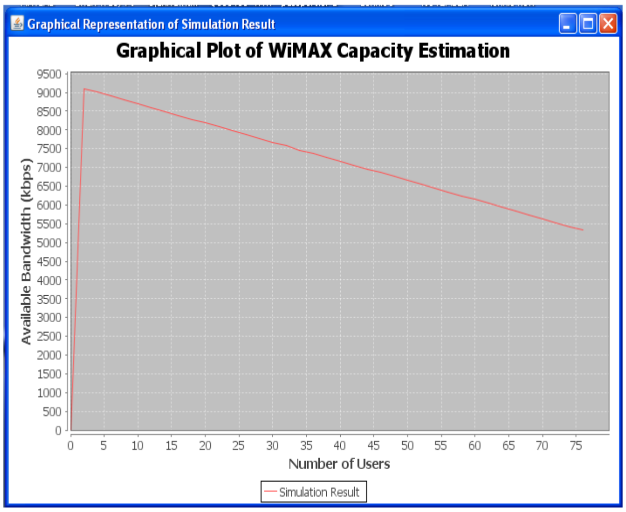

Fig. 5. Graphical representation of the available bandwidth to the number of subscribing users.

B. *Case Study II*

In case study II, we simulated using a channel bandwidth of 10MHz while some other system and service class parameters were changed.

In this test case, the service class parameters in Table VIII are kept the same like in Table VI, while the channel bandwidth and the cyclic prefix rate of the system class parameters were changed as shown in Table IX in an efficient way to benefit a higher capacity.

The channel bandwidth and cyclic prefix were changed to 10MHz and 1/16 respectively as shown in Table IX.

The result obtained when compared to that obtained in case study I shows the maximum number of users that can be supported by the base station increased to 167. This is because increasing the channel bandwidth results in an increase in throughput and hence the number of users been accommodated. Assigning a cyclic prefix rate of 16 as in case study II, implies that 1/16 of the useful symbol duration is repeated at the beginning of each symbol. Thus the system suffers less overhead and increase in throughput when compared with a lesser cyclic prefix index.

TABLE VIII: OFDMA SERVICE CLASS PARAMETERS FOR CASE STUDY II

Subscribers Class	Data Rate	Percentage (%)	Contention Ratio	Over Subscription Ratio
Business Class	2000	40	10	50
Residential Class	512	60	30	50

TABLE IX OFDMA SYSTEM CLASS PARAMETERS FOR CASE STUDY II

Channel Bandwidth	Subframe Ratio	Cyclic Prefix Rate	DL/UL Ratio	PDU's Per Data Burst	Connections per PDU
10	3/1	1/16	4	2	2

The graphical representation in Fig. 7 shows the summary of the result obtained in case study II.

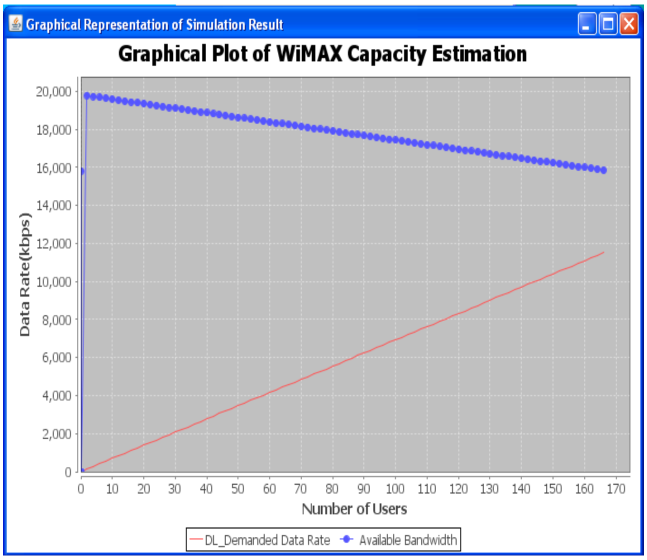

Fig. 6. Graph showing the demanded data rate (DL) and available bandwidth for study case II.

From the graphical plot shown in Fig. 7, it can be seen that the bandwidth demand of the 168th user can not be afforded in the DL direction. Also the peak available data rate in DL increased to 19803.3 kbps when compared to that of case study I. It also then decreases to 15827.5 kbps as the number of connecting users approached 167. The minimum demanded data rate for 167 simultaneously connecting users in the DL sector is approximately 11577.1 kbps.

C. *Study Case III*

In this case study, we simulated using channel bandwidth of 5MHz while some other system and service class parameters were changed.

In Table X, the demanded data rate of the service class parameters is increased and a channel bandwidth of 5MHz is used in Table XI while keeping all other system class parameters constant. The maximum number of users supported and its effect on the capacity evaluation is observed.

TABLE X: SERVICE CLASS PARAMETER FOR CASE STUDY III

Subscribers Class	Data Rate	Percentage (%)	Contention Ratio	Over Subscription Ratio
Business Class	2700	45	10	50
Residential Class	1000	55	30	50

TABLE XI: SYSTEM CLASS PARAMETER FOR CASE STUDY III

Channel Bandwidth	SubFrame Ratio	Cyclic Prefix Rate	DL/UL Ratio	PDU's Per Data Burst	Connections per PDU
5	3/1	8	4	2	2

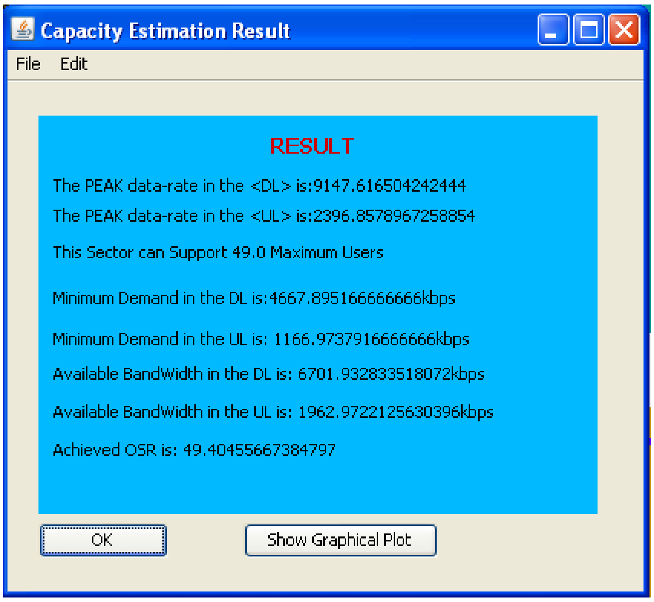

Fig. 7. Capacity result interface for case study III.

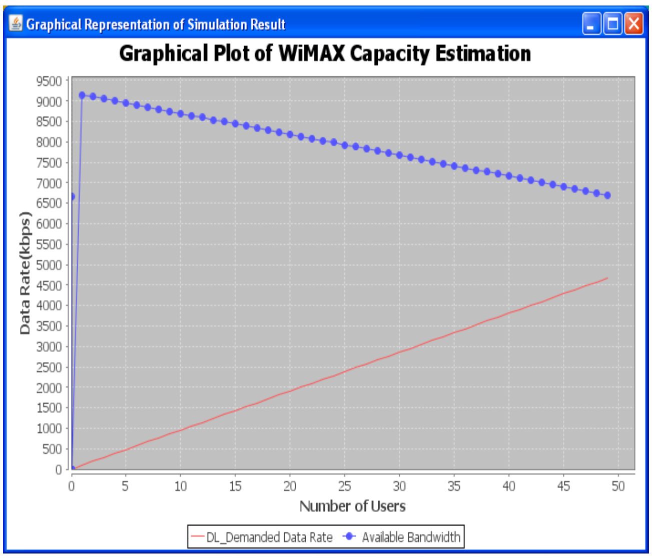

Fig. 8. Graph showing the demanded data rate (DL) and available bandwidth study case III.

Using the parameters in the above Tables in case study III, the result obtained in Fig. 7 shows that the base station can support a total of 49 mixed users. This shows that the total number of users supported by the base station decreases as the demanded data rate increases.

The WiMAX capacity result is summarized in Fig. 7. The graphical representation of the result is shown in Fig. 8. From the graphical plot, the peak data rate is 9147.62 kbps which decreases to 6701.93 kbps when the number of users reaches maximum. Minimum demand for the last user to be supported is 4667.9 kbps.

VI. CONCLUSION

In this paper, Mobile WiMAX capacity is estimated. The algorithm for the calculation of the maximum number of users per BS is evaluated and the effect of overhead is estimated. Knowing that the capacity of any network is affected by overhead, its effect is analyzed and shown as it affects capacity calculation and estimation. The essence of overhead removal method is to estimate the exact available data rate. For the estimation of the average capacity, we assumed a modulation and an application distribution within the area of interest. With the understanding of the system's raw capacity and the effect of the overheads associated with MAC and PHY layers on capacity of mobile WiMAX, we have simulated with our result showing how the numbers of users are reduced when the data rate of user is increased. We also estimated how the number of users increases when the channel bandwidth and cyclic prefix increased.

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