



Improvement in Channel Capacity and Cell Range within User Cluster in WiMax

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Abstract: The opportunity for WiMAX to serve those people who want to switch to broadband service is huge in many parts of the world where wired technologies may not be practicable. The presented methodology would help those operators that plan to implement a wide coverage network in a city. Using the introduced methodology, service providers will be able to estimate the number of base stations and hence the network investment and profitability. In this paper we study the factors influencing system bandwidth capacity in IEEE 802.16e networks. Additionally, we investigate and evaluate the system capacity of 802.16e in order to understand how the relay architecture can lead to capacity increases in the downlink. An analytical study of the WiMAX propagation channel by using Cost-231 Hata Model is presented. This model performed in different frequency bands; the Signal to Noise Ratio (SNR) is achieved under different frequency band as well. The useful bandwidth for WiMAX in the downlink helped us to calculate the maximum numbers of subscriber station (SS) based on traffic modeling. Numerical results and discussion highlight the effect of factors over WiMAX capacity; we also simulate in MATLAB the modeling for different system parameters and traffic cases to ease the mobile WiMAX planning.

Keywords: WiMAX capacity, IEEE802.16, mobile WiMAX, SNR, Cost-231 Hata

I. INTRODUCTION

There are multiple physical-layer choices, within IEEE 802.16 standard. Similarly, there are multiple choices for MAC architecture, duplexing, frequency band of operation, etc. So, we can say that IEEE 802.16 is a collection of standards, not one single interoperable standard. To provide interoperability the WiMAX Forum defines a limited number of system profiles and certification profiles. A System Profile defines the subset of mandatory and optional physical and MAC-layer features selected by the WiMAX Forum from the IEEE 802.16-2004 or IEEE 802.16e-2005 standard. By now two different system profiles are defined: one based on IEEE 802.16-2004, OFDM PHY, called the fixed system profile; the other one based on IEEE 802.16e-2005 scalable OFDMA PHY, called the mobility system profile. The Mobile WiMAX standard has been developed to be the best wireless broadband standard for portable devices enabling a new era of high throughput and high delivered bandwidth together with exceptional spectral efficiency when compared to other 3G+ mobile wireless technologies[1, 4].

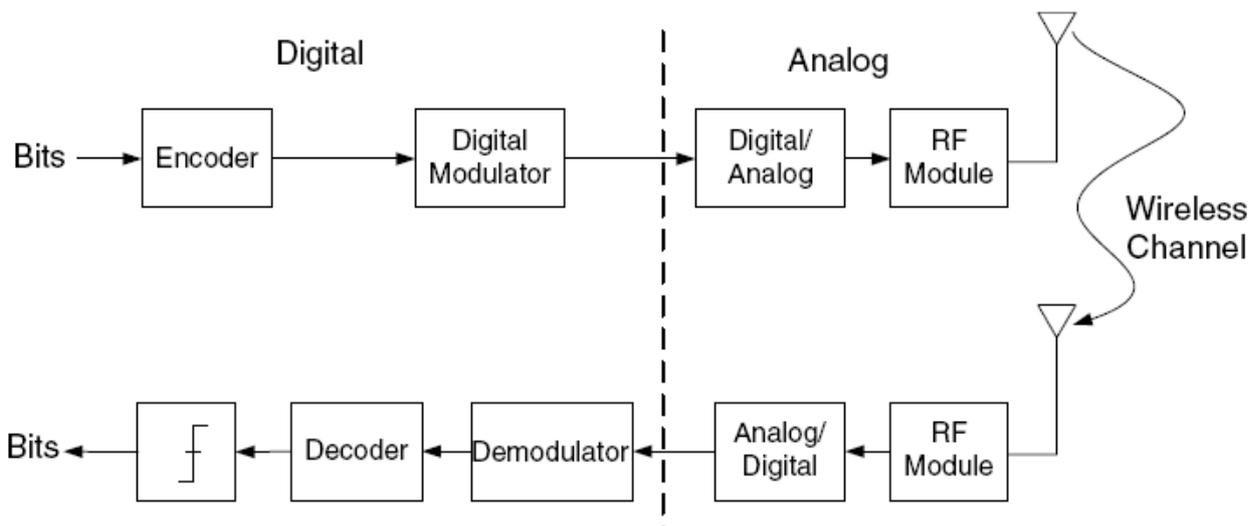


Figure 1- Wireless channel model

A wireless channel can be modeled as Figure 1.

The transmitter receives packets of bits from a higher protocol layer and sends those bits as electromagnetic waves toward the receiver. The key steps in the digital domain are encoding and modulation. The encoder generally adds redundancy that will allow error correction at the receiver. The modulator prepares the digital signal for the wireless channel and may comprise a number of operations. The modulated digital signal is converted into a representative analog waveform by a digital-to-analog convertor (DAC) and then up converted to one of the desired WiMAX radio frequency (RF) bands. This RF signal is then radiated as electromagnetic waves by a suitable antenna. The receiver performs essentially the reverse of these operations [5].

II. COVERAGE AND CELL RANGE

The following relation holds for all transmission lines included wireless channels.

$$P_r = P_t + G_t - PL + G_r \quad \dots (1)$$

where: P_r is the minimum received power in the receiver.

P_t is the transmitted power.

G_t is the gain of the transmitter

G_r is the gain of the receiver.

PL is the PathLoss

Sensitivity or minimum received power can be calculated manipulating the formula below:

$$P_{r,\min} = -114 + SNR_{Rx} - 10 \log R + 10 \log \left(\frac{F_S N_{used}}{N_{FFT}} \right) + ImpLoss + NF \quad \dots(2)$$

As can be seen P_r min depends receiver SNR, SNR_{Rx} , That is defined in the standard based on different modulation levels and channel coding rates. $ImpLoss$ is the implementation loss, which includes non-ideal receiver effects such as channel estimation errors, tracking errors, quantization errors, and phase noise. The assumed value is 5 dB. NF is the receiver noise figure, referenced to the antenna port. The assumed value is 8 dB.

P_t , G_t , G_r are specific productions values introduced with the manufacturers.

The term Pathloss (PL) here, generally, involves all different type of losses within the transmitter and receiver included large scale losses and also fading impact and not only the loss caused by distance. However in short distances and because of simplicity, in Free Space Modeling the obstructions between the transmitter and receiver are neglected [1-3].

$$PL(d) = 32.44 + 20 \log_{10}(f) + 20 \log_{10}(d) \quad \dots(3)$$

The above relation for free space pathloss calculation is a d (cell range) dependent function. It implies that, obtaining minimum received power from (eq-1.8), maximum pathloss can be calculated using (eq-1.7). Finally, the maximum cell range value (d), which introduces our coverage radius can be calculated using (eq-1.9), where the parameter f represents the used carrier frequency.

Rather than free space model there are many different well-known relations to calculate the maximum pathloss called Propagation Models. Other parameters are defined in such models to consider the environmental effects in our calculations. These parameters divide the environment under study into Urban, Suburban and rural areas. Other coefficients are present in different pathloss calculation methods to suit the conditions as best as possible such as: the average antenna height of mobile and base stations, the type of the terrains in each area, frequency and fading correction factors and so forth. Some examples of propagation models are: COST-231 Hata or Walfisch-Ikegami, SUI model and Multihop Path Loss Model [6].

III. OFDMA

The total capacity available with a base station is shared among multiple users on a demand basis, using a burst TDM scheme. When using the OFDMA-PHY mode, multiplexing is additionally done in the frequency dimension, by allocating different subsets of OFDM subcarriers to different users. This is done based on sub-channelization method. Subchannelization is the method that differentiates OFDMA with OFDM. The available subcarriers within the total bandwidth can be divided into several groups of subcarriers called subchannels. Subchannels can be assigned to the users on a logical procedure based on user demands and channel conditions. OFDMA is essentially a hybrid of FDMA and TDMA: Users are dynamically assigned subcarriers (FDMA) in different time slots (TDMA). There are 4 different types of subcarriers in an OFDMA symbol. Data subcarriers and Pilot subcarriers (used for estimation and synchronization purposes). These two first types are considered Active subcarriers. DC subcarriers together with Guard subcarriers (used for guard bands) are commonly denominated as Null subcarriers. Figure 2 illustrates the OFDMA symbol's subcarrier structure [4].

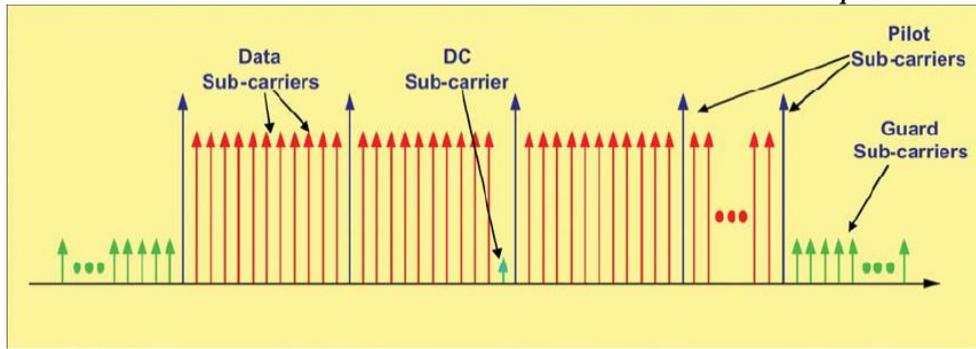


Figure 2 - Frequency domain representation of OFDMA symbol [4]

The number and exact distribution of the subcarriers that constitute a subchannel depend on the subcarrier permutation mode. A distributed subcarrier permutation draws subcarriers pseudo-randomly to form a subchannel and provides better frequency diversity, whereas an adjacent subcarrier distribution allows the system to exploit multiuser diversity. In general, distributed (diversity) permutations perform well in mobile applications while adjacent (contiguous) permutations are well appropriated for fixed, portable or low mobility environments. In order for each MS to know which subcarriers are intended for it, the BS must broadcast this information in downlink MAP messages. Figure 3 reveals a graphical comparison between OFDM and OFDMA considering 4 different users sharing same bandwidth in both techniques in the uplink.

In the MAC layer, one or more service data units (SDU) are encapsulated into a protocol data unit (PDU), which is appropriately modulated and mapped onto a PHY frame. The DL-MAP and a compressed MAP are the broadcasting message; and either of these MAP is the first MAC management message located in the frame. In order to reveal the redundant factors of DL-MAP, we will first examine elements of the MAC PDU since DL MAP is also a MAC PDU [8]. The MAC PDU format of IEEE 802.16 is illustrated in Figure 3.

The MAC PDU may be mapped onto data sub-carrier of the PHY frame by the following equation:

$$N_{d-sub} = \frac{B}{RMC} \dots (4)$$

Where B is the number of bits of in the MAC PDU, M is the number of bits for a subcarrier under a byte of modulation, C and R are the coding rate and the number of repetitions respectively.

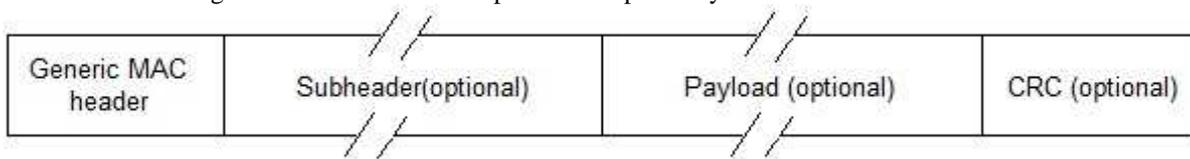


Figure 3: MAC PDU formats [7].

We define the MAC data rate (MDR) as the transmission rate of the data bursts in the frame. This is represented as:

$$\text{MAC data-rate} = \frac{N_t \text{bits} - O_H \text{bits}}{T_f} (\text{bits/s}) \dots (5)$$

Where the total number of bits N_t bits represent the total bits that a frame transfers within a frame duration and overhead bits, O_H bits are the number of bits used for non-data control message. This include preamble, FCH, DL-MAP, UL-MAP etc. The number of symbols in the TDD/ OFDMA frame in Fig. 1 is calculated from the expression

$$N_{symbol} = \frac{T_f - (TTG + RTG)}{T_s} \dots (6)$$

Where the symbol time is equal to $T_b + T_g$, a useful symbol time is $1/\Delta f$ subcarrier spacing and cyclic prefix time T_g is T_b . G The subcarrier spacing can be obtained using the channel bandwidth BW , sampling factor n and FFT size N_{FFT} . According to standard, the sampling frequency F_S is $(n \cdot BW / 8000) \times 8000$ and the subcarrier spacing Δf is F_S / N_{FFT} . Therefore, the symbol time is

$$T_s = T_b + T_g = T_b + T_b \cdot G = (1 + G) T_b = (1 + G) / \Delta f = (1 + G) \cdot N_{FFT} / F_S \dots (7)$$

And thus

$$N_{symbol} = \frac{T_f - (TTG + RTG)}{(1 + G) N_{FFT}} \dots (8)$$

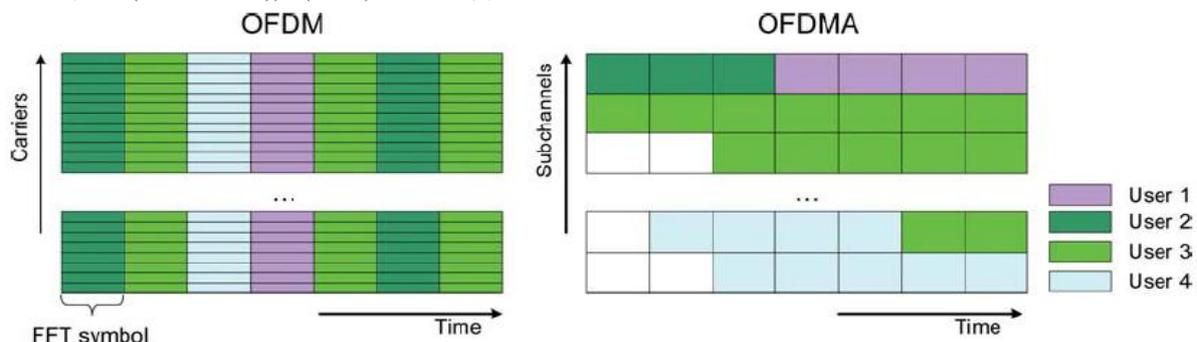


Figure 4 - OFDM and OFDMA channel allocation in uplink [4]

Table 1 - OFDM symbol parameters for Fixed WiMAX and the equivalent OFDMA symbol parameters used in Mobile WiMAX in downlink [6].

Parameter	Fixed WiMAX OFDM-PHY	Mobile WiMAX Scalable OFDMA-PHY ^a
FFT size	256	128, 512 , 1,024, 2,048
Number of used data subcarriers ^b	192	72, 360 , 720, 1,440
Number of pilot subcarriers	8	12, 60 , 120, 240
Number of null/guardband subcarriers	56	44, 92 , 184, 368
Cyclic prefix or guard time (Tg/Tb)	1/32, 1/16, 1/8 , 1/4	
Oversampling rate (Fs/BW)	Depends on bandwidth: 7/6 for 256 OFDM, 8/7 for multiples of 1.75MHz, and 28/25 for multiples of 1.25MHz, 1.5MHz, 2MHz, or 2.75MHz.	
Channel bandwidth (MHz)	3.5	1.25, 5 , 10, 20
Subcarrier frequency spacing (kHz)	15.625	10.94
Useful symbol time (μs)	64	91.4
Guard time assuming 12.5% (μs)	8	11.4
OFDM symbol duration (μs)	72	102.9
Number of OFDM symbols in 5 ms frame	69	48.0

a. Boldfaced values correspond to those of the initial mobile WiMAX system profiles.
b. The mobile WiMAX subcarrier distribution listed is for downlink PUSC (partial usage of subcarrier).

IV. SOFDMA

The mobile WiMAX - IEEE 802.16e-2005, is based on Scalable Orthogonal Frequency Division Multiple Access. The available bandwidth for WiMAX can vary based on the local frequency usage over the globe and the scalability is developed to support these worldwide variations. Therefore SOFDMA refers to the capability of choosing the number of subcarriers according to the available bandwidth. The channel bandwidth can vary from 1.25 MHz to 20 MHz and thus, a number of 128 to 2048 subcarriers can be assigned to each bandwidth correspondingly [9-11].

Table 1 summarizes the OFDM symbol parameters for Fixed WiMAX (IEEE 802.16-2004) and the equivalent OFDMA symbol parameters used in Mobile WiMAX (IEEE 802.16e-2005) in downlink direction. The diverse values for parameters in OFDMA refer to the scalability concept.

V. PROPOSED METHODOLOGY

1. Define the service class parameter such as data rates, contention ratio and percentage of residential class subscribers for the different classes like residential and business.
2. Define the value of OVER SUBSCRIPTION RATIO by using the formula
3. $C_{ref} = FFT_{used} / 2 T_s$ (1)

where the values for FFT_{used} and T_s depend on the channel bandwidth and the Cyclic Prefix factor respectively. Assume that the residential class occupies 58% of the users under cover of our base station while the business class users are confined to 42%. In this case the total capacity for OSR calculation would be:

$$C_{tot} = N * (58\% * 512 + 42\% * 1000) \quad (2)$$

$$OSR = C_{tot} / C_{ref} \quad (3)$$

Where N refers to the number of users that are connected to the base station.

4. Define value of system parameter- channel bandwidth either it is 5MHz or 10 MHz. In case of bandwidth 5 MHz the number of data sub-carriers is 360 for FFT downlink and 272 for FFT uplink and the number of sub-channels considering PUSC (Partial usage of subcarrier) for downlink is 15 and for the uplink are 17.
5. But in case of bandwidth 10 MHz the number of data sub-carriers is 720 for FFT downlink and 560 for FFT uplink and the number of sub-channels considering PUSC for downlink is 30 and for the uplink are 35.

6. Further define the value of cyclic prefix rate, DL portion, and UL portion and traffic ratio.
7. The average number of connections per PDU, the average number of PDUs per data burst and (T_b) Fixed Useful OFDM symbols duration (ms) values are taken.
8. Calculate the value for Total symbol duration $T_s = T_g + T_b$

$$= (G+1) T_b \quad (4)$$

Where G is the ratio of T_g and T_b . This value can be 1/4, 1/8, 1/16 or 1/32. T_b is $1/\Delta f$, with the sub-carrier spacing Δf given as

$$\Delta f = F_s / N_{FFT} \quad (5)$$

$$F_s = \text{floor} (n BW / 8000) * 800 \quad (6)$$

Where F_s is the sampling frequency, n is the sampling factor, BW is the nominal channel bandwidth and N_{FFT} is the number of points for FFT or total number of subcarriers.

9. Now calculates the available data-rate in the uplink by removing the overheads originated from the system configuration and additional users.
- i. Calculate the bandwidth of the DL and UL channel by using the formula

$$BW = FFT_{used} / T_s * \sum (\% p. k. OCR) \quad (7)$$

Where FFT_{used} is the number of data subcarriers that is dependent on the channel bandwidth, the direction and its permutation scheme.

$\%P$ stands for the percentage (weight), k for number of bits per symbol and OCR for the overall coding rate.

- ii. Length of the uplink/ downlink frame is calculated by

$$BW_2 = TUL = UL / (UL + DL) * BW1 \quad (8)$$

$T_f = 5ms$ is the frame duration.

Length of the Uplink and Downlink subframe (based on DL/UL ratio)

$$T_{UL} = UL / (UL + DL) * T_f \quad (9)$$

$$T_{DL} = DL / (UL + DL) * T_f \quad (10)$$

- iii. Transition gap duration is $T_g = 11.4\mu s$ are fixed values in Mobile WiMAX.
- iv. Now the complete symbols (N_{S-DL} or N_{S-UL}) can be embedded in the downlink or uplink subframe (T_{DL} or T_{UL}) is

$$N_{S-DL} = \lfloor (T_{DL} - T_g) / T_s \rfloor \quad \text{and} \quad (11)$$

$$N_{S-UL} = \lfloor (T_{UL} - T_g) / T_s \rfloor \quad (12)$$
- v. Now remove the subframe overhead by using formula

$$BW_3 = \lfloor (N_{S-DL} * T_s) / T_{DL} \rfloor * BW_2 \quad \text{and} \quad (13)$$

$$BW_3 = \lfloor (N_{S-UL} * T_s) / T_{DL} \rfloor * BW_2 \quad (14)$$

- vi. Now, we need to remove this extra symbol from our useful DL or UL bandwidth

$$BW_4 = (N_{S-DL} - 1) * BW_3 \quad \text{and} \quad (15)$$

$$BW_4 = (N_{S-UL} - 1) * BW_3 \quad (16)$$

- vii. To reduce the amount of bandwidth wasted in sending small packets, the MAU can be calculated in bytes:

$$MAU = \lfloor (N_C * OCR) / N_{Sub-CH} \rfloor \quad (17)$$

Where N_C the coded block size in bytes and OCR is the coding rate of the most robust in use modulation scheme, here 64-QAM as the worst case, and N_{Sub-CH} is the number of sub-channels based on the system's channel bandwidth using PUSC permutation.

- viii. The interval between contention allocations is configurable by the operator by

$$N_{contention} = \lfloor T_f / 100 \rfloor * \lfloor \{ (n * 100) / MAU \} + 1 \rfloor / N_{S-UL} \quad \text{and}$$

$$N_{contention} = \lfloor T_f / 100 \rfloor * \lfloor \{ (n * 100) / MAU \} + 1 \rfloor / N_{S-DL} \quad (18)$$

The contention overhead is removed by

$$BW_5 = BW_4 * (1 - contention) \quad (19)$$

- ix. Number of MAC PDU and number of MAC data burst for the uplink is given by

N_{PDU} = No. of users/ average no. of connections per PDU

And the overall overhead bytes imposed by PDUs would be:

$$MAC_PDU = N_{PDU} * (6+4+3+2) \text{ Bytes.} \quad (20)$$

MAC_PDU overhead(bytes)(6Generic(MH)+3Fragmentation/Packing(SubH)+2GrantManagement(subH)+4CRC)

MAC data burst is given by

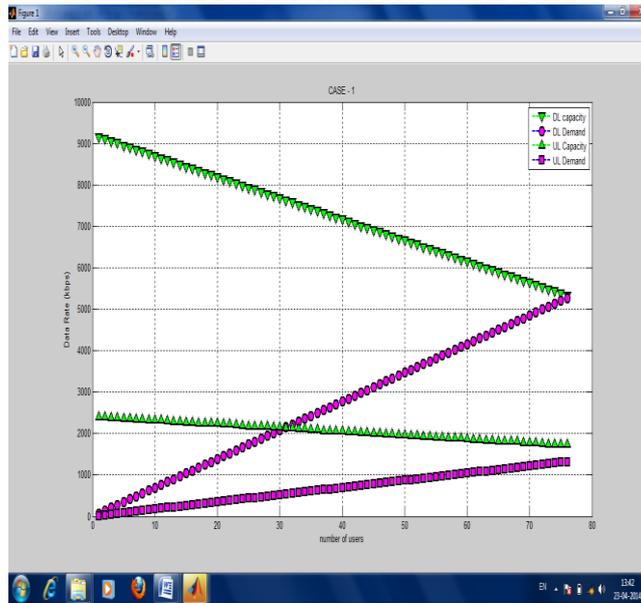
MAC_BURST = MAC_PDU / average no. of PDU per Data burst

10. Now again calculate the value of OSR.

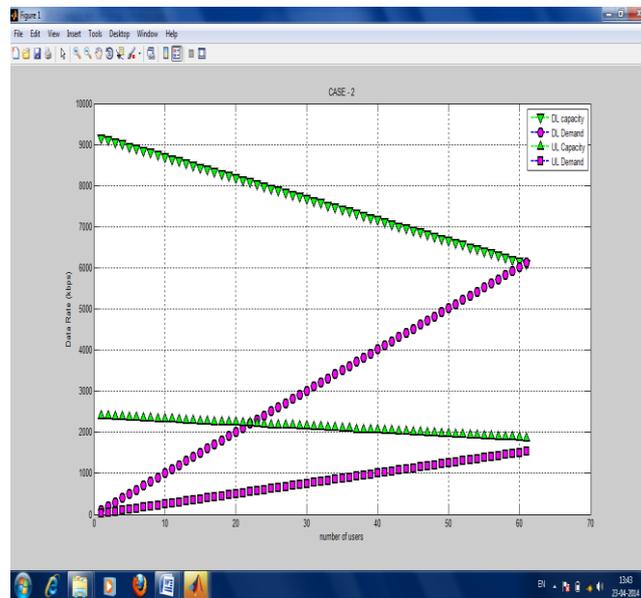
11. Now compares the available BW (after removing the overheads caused by the system configuration based the number of users) with minimum required data-rate to support users 'demand according to the subscribers classes based on the number of users) in both DL and UL. OSR is calculated as the number of users raises and is compared with OSR.

12. Plot and compare the result.

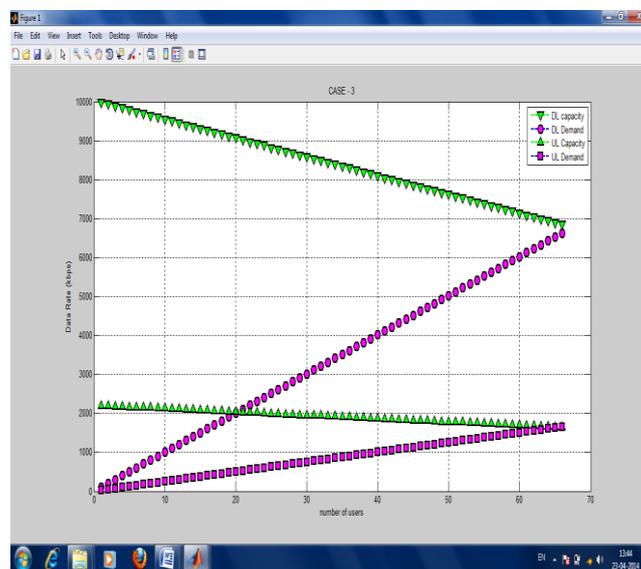
VI. IMPLEMENTATION and RESULTS



Case-1 result



Case-2



Case-3

	MIN-DEMAND in the <DL> (kbps)	MIN-DEMAND in the (kbps)	AVAIL ABLE BW in the <DL> (kbps)	AVAILAB LE BW in the (kbps)	OSR	users supporta ble	PEAK data-rate in the <DL> (kbps)	PEAK data-rate in the (kbps)
Case 1	5268.62	1317.16	5327.1	1733.89	48.069	76	9147.62	2396.86
Case 2	6124.77	1531.19	6084.8	1854.5	62.723	61	9147.62	2396.86
Case 3	6626.8	1656.7	6844.1	1648.69	64.094	66	9969.97	2194.69

As can be observed, in this case-1, based on the input parameters, 76 users can be supported with the specified sector. This is where according to the output data, the limitation of the algorithm is concerned with the Downlink capacity in case-1. In other words, the sector with the specified parameters can support 76 mixed traffic users based on the modulation and application distribution assumptions and the traffic demand, while the bandwidth demand of the 77th user cannot be afforded in the DL direction. The peak available data-rate in DL is 9147.62 kbps that decreases to 5327.19 kbps as the number of users reaches to 76. The minimum demand data rate for 76 simultaneously connecting users is 5268.62 kbps that can be fulfilled with the available bandwidth in the DL.

In Case-2, the system parameters are kept the same as Case-1. Only the Service class parameters are changed as indicated in the table. Since, the subscribers in both residential and business service classes are assigned higher data-rate values, the number of users that a sector with the same specified system parameters as Case-Staudy-1 can serve is expected to be less i.e. 61 subscribers, the system parameters in two experiments are the same, the peak data-rates are identical.

OSR value in Case-1 is less than the corresponding value in the Case-2. This is while the maximum amount of supportable users in the first is even greater than the subscribers in second case. The fact is that the OSR value is related to the portion of the offering data-rate that can be served with the lowest modulation scheme (BPSK). Since test 2 is offering more data-rate per user, it suffers more over subscription ratio. If the desired OSR value in the Case-Staudy-2 would be the same as Case-Staudy-1, this value could be the limitation factor for the maximum number of users.

In third case, the service class parameters are kept same, while it has been tried to change the system parameters in an efficient way in order to benefit a higher capacity. In this case we have maximum number of minimum demand data rate with the available bandwidth in the DL. We also have the maximum value for OSR and number of subscribed user is more than the third case.

VII. CONCLUSION

In Case-3, this time the service class parameters are kept the same as Case-2, while it has been tried to change the system parameters in an efficient way in order to benefit a higher capacity. The system is again based on 5MHz channel width and with DL/UL Traffic Ratio=4. Basically, in this test we try to manipulate the configurable system parameters in order to maximize the number of users that can be covered with the sector. One of these parameters is DL:UL Ratio. As in former test the limitation was concerned with the downlink, by assigning a greater portion to the DL-subframe we can increase the total capacity. Thus a DL:UL Ratio of 7:2 is assigned in Case-3 instead of the former value of 3:1 in Case-2. Furthermore, by choosing a higher level Cyclic Prefix Index we can achieve less overhead and hence greater throughput. Assigning a CP=16 in Case-3 implies that 1/16 of the useful symbol duration is repeated at the beginning of each symbol. Thus the system suffers less overhead when compared with Case-2 where CP=8. Note that the cyclic prefix is used to eliminate the inter symbol interference. Therefore, in new CP-index assignment the channel's delay spread and interference conditionings must be considered. As can be observed in the results, the new system parameters in Case-3 introduce a greater peak data-rate in the downlink so that the sector can support more users in this direction. Note that the DL:UL Ratio assignment must be done in an efficient way to provide both directions with the required capacity. The system based on the new parameters in Case-3 can support 66 subscribers that are 5 more user compared with Case-2. Although this time the algorithm limitation is concerned with the uplink, the downlink stream is also efficiently occupied. In other words, in Case-Study-3 the system capacity and demand are matched in an optimized way, as both DL and UL entire capacities are efficiently filled with each direction's traffic demand.

VIII. FUTURE WORK

As Mobile WiMAX is a novel standard and not many certified products are available in the market nor many trials and deployments are made, it can be seen as a topic that has huge researching potentials. Many specialists believe that the future 4G platform will be formed as a combination of LTE and WiMAX standards. So the most controversy would be upon the global market share for each of these mobile broadband technologies. Therefore, each of the innovate service providers are competing to include the state-of-art technologies in their supporting standard as soon as they appear.

Advanced releases of Mobile WiMAX will implement a considerable number of innovative technologies such as; SIMO, MIMO, AAS and beam forming. Utilization of each of these techniques can affect the capacity by increasing the total throughput and resource efficiency, via different signaling procedure. On the other hand, new amendments such as higher velocity support are an example of applications that will restrict the system's actual throughput. Therefore, upgrading the capacity algorithm presented in this thesis based on these additional features can be looked as an interesting future work.

Furthermore, the scheduling process and mobility handling procedures will be updated constantly to meet the QoS of demanded WiMAX applications. Therefore, the presented traffic modeling scheme can be a commencement of any further developments to guarantee the subscribers' data-rates.

Finally, developing a user friendly planning tool by exploring the capacity calculations and propagation and coverage modeling that covers the overall network considerations over a city-wide implementation would be a great area of interest for researchers and software developers.

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