The Overhead and Efficiency Analysis on WiMAX's MAC Management Message

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***Abstract*—This paper presents the overhead analysis on MAC Management Messages of WiMAX based on IEEE802.16 standard. The efficiency on the MAC layer is derived for Point to Multipoint (PMP) topology. The influence of several parameters is examined. The parameters, such as the number of subscriber stations in the network, various modulation and coding, and length of MAC message's PDUs, are assigned as the overhead parameters. The results show the specified parameters have significant impact on the efficiency of MAC layer. Finally, some recommendations to reduce the overhead are put forward.**

Index Terms — *WiMAX, IEEE802.16; MAC efficiency; MAC overhead*

I. Introduction

The Worldwide Inter-operability for Microwave Access (WiMAX) is a telecommunication technology based on IEEE802.16 standard [1]. WiMAX network overcome some of the limitations of IEEE 802.11, e.g. limited range or insufficient Quality of Service support, and also introduce full mobility [2]. Using their conjunction it is possible to create a solution for metropolitan and local area networks.

WiMAX supports two types of network topologies i.e. Point to Multipoint (PMP) and Mesh. In PMP, the link connection is only between Base Station (BS) and Subscriber Station (SS). A connection, used for the purpose of transporting Medium Access Control (MAC) management messages, required by the MAC layer.

The overhead caused by the MAC layer of the network is an important performance indicator, because it significantly influences the throughput. It is interesting to make an analysis how the MAC efficiency is dependent on the physical and logical setups of the network. Performance of a networking protocol is commonly evaluated by means of the net throughput, especially on MAC layer, and delay. The focus of this paper is the MAC layer efficiency.

Many papers evaluate MAC performance of the IEEE 802.11 standard. In [3] the authors study the influence of MAC overhead in IEEE 802.11 ad-hoc networks. The analysis in [4] investigates MAC performance of the IEEE 802.16 and the amendment IEEE 802.16a. The focus is on the PMP topology and for a simple scenario, using one base station and one subscriber station, the net bit rate on the MAC level is calculated.

The authors in [5] analyze the MAC efficiency dedicated to multi-hop wireless networks based on IEEE 802.16a standard. The IEEE 802.16a air interface is described and a multi-hop approach for PMP mode is defined. Net throughput on MAC layer is then presented for one chosen multi-hop scenario. The number of hops is carried out as the parameter.

The remainder of this paper is organized as follows: In Section II, the IEEE802.16 reference model mainly for the PMP mode is described. Section III determines the MAC messages overhead as well as the efficiency of MAC layer. The net throughput analysis is also carried out in this section. Results of MAC overhead and the efficiency are shown in section IV. We also discussed the simulation results. The last section provides our conclusions.

II. IEEE802.16 Reference Model

A. MAC Layer Functionality

The reference model is shown in Figure 1. It can be seen that the MAC consists of three sub-layers [6][7].

The Service-Specific Convergence Sub-layer (CS) is used for mapping of external network data into MAC service data units (SDUs) received by the MAC common part sub-layer (CPS). The MAC CPS isn't required to parse any information from the CS payload.

The MAC CPS provides the core MAC functionality of system access, bandwidth allocation, connection establishment, and connection maintenance. The separate security sub-layer provides authentication, secure key exchange and encryption. The MAC management messages are part of MAC CPS.

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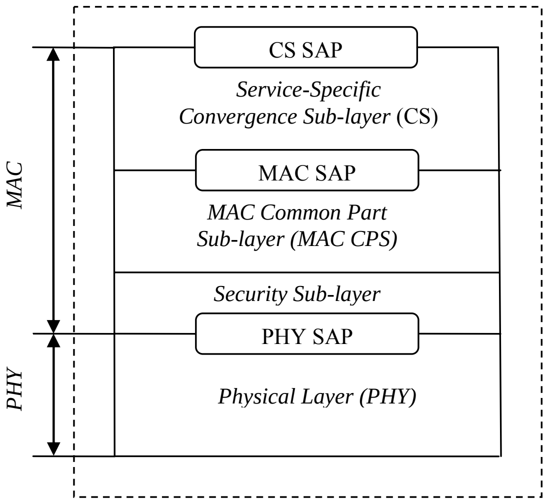

Fig.1. IEEE 802.16 – layer model – data/control plane

B. PMP Topology

In this topology a central BS operates with a sectorized antenna capable of handling multiple independent sectors simultaneously. Within a given frequency channel and antenna sector, all stations receive the same transmission. The subscriber stations communicate only with the BS and not with each other. This scenario is shown in Figure 2.

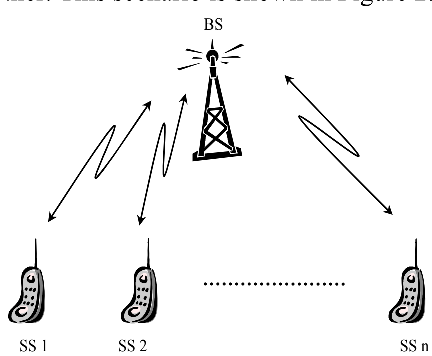

Fig.2. Point to Multipoint topology

In downlink, the BS is the only transmitter, so that it doesn't have to coordinate with other stations, except for the overall time division duplexing (TDD) when time is divided into uplink and downlink transmission periods. In the uplink direction, SSs transmit on a demand basis. A SS may have continuing rights to transmit, or the rights may be granted by the BS after receipt of a request.

The MAC operates in a connection-oriented mode. After SS registration, connections are associated with service flows to provide a reference against which to request bandwidth. Service flows provide a mechanism for uplink and downlink quality of service (QoS) management. In addition, bandwidth is granted by the BS to an SS as an aggregate of grants in response to per connection requests from the SS.

Once the connections are established, they may be maintained during their existence, and may be terminated. The maintenance requirements depend on the type of selected service.

C. Physical OFDM Symbols Parameters

According to the standard, four primitive parameters are defined to characterize the OFDM symbol:

- BW – nominal channel bandwidth,
- N_{used} – number of used subcarriers,
- n – sampling factor, in conjunction with BW and N_{used} determines the subcarrier spacing and the useful symbol time,
- G – ratio of CP time to useful time.

Using these primitive parameters another derived parameters are identified:

- N_{FFT} – smallest power of two grater than N_{used},
- Sampling frequency; $F_s = \lfloor n \cdot BW / 8000 \rfloor \cdot 8000$,
- Subcarrier spacing; $\Delta f = F_s / N_{FFT}$,
- Useful symbol time; $T_b = 1/\Delta f$,
- CP Time ; $T_g = G \cdot T_b$,
- OFDM symbol time; $T_s = T_b + T_g$,
- Sampling time ; T_b / N_{FFT}.

Possible values of G are 1/4, 1/8, 1/16 and 1/32. The sampling factor has different values for bandwidths that are being multiples of different frequencies.

N_{used} is specified as 200 which mean that N_{FFT} is 256. Therefore the number of lower frequency guard subcarriers is equal to 28, the number of higher frequency guard subcarriers is 27. Thus, together with the DC carrier, the number of null subcarriers is 56 [2]. After subtracting 8 pilot subcarriers, there are 192 subcarriers available for data transmission.

D. Channel Coding/Modulations

The channel coding process is composed of three steps: randomizing, forward error correction (FEC) and interleaving. During transmission they are applied in this order, during reception their order is reversed. The mandatory channel coding with different modulations used in this paper can be seen in table 1.

Encoded data bits are then interleaved by an interleaving block with a block size corresponding to the number of coded bits per the allocated subchannel per OFDM symbol (N_{cbps}). For BPSK, QPSK, 16-QAM and 64-QAM, this number is 1, 2, 3 and 6, respectively.

III. The Efficiency on MAC Layer

The MAC overhead can be evaluated by means of determining the efficiency of the MAC layer. According to [5] the MAC efficiency can be defined as the ratio of the net throughput on MAC layer and the throughput per OFDM symbol.

$$\eta = \frac{\Theta_{MAC\ net}}{\Theta_{OFDM\ symbol}} \quad (1)$$

TABLE I.
MANDATORY CHANNEL CODING/MODULATION

Modulation	*Uncoded block size (bytes)*	*Coded block size (bytes)*	*Overal coding rate*
BPSK	12	24	1/2
QPSK	24	48	1/2
QPSK	36	48	3/4
16-QAM	48	96	1/2
16-QAM	72	96	3/4
64-QAM	96	144	2/3
64-QAM	108	144	3/4

The net throughput on the MAC layer is defined by equation 2. It is the ratio of the total number of payload bits, i.e. without all MAC overhead, in a frame to the frame duration T_{frame}.

$$\Theta_{MAC\ net} = \frac{\sum Payload\ bits}{T_{frame}} \quad (2)$$

The throughput of an OFDM symbol is given by:

$$data\,rate = \frac{number of\ uncoded\,data\,bits\ per\,OFDM\,symbol}{OFDM\,symbol\,duration} \quad (3)$$

Equation 4 shows the calculation in a more symbolic way, where N_{used} is the number of used OFDM subcarriers, N_{pilot} is the number of OFDM pilot subcarriers, N_{cbps} is the number of coded bits per allocated symbol (e.g. $N_{cbps} = 6$ for 64-QAM) and C is the code rate.

$$\Theta_{OFDM\ symbol} = \frac{\left(N_{used} - N_{pilot}\right)\cdot N_{cbps}\cdot C}{T_{symbol}} \quad (4)$$

The number of uncoded bytes per symbol is given as:

$$BpS = \frac{\left(N_{used} - N_{pilot}\right)\cdot N_{cbps}\cdot C}{8} \quad (5)$$

Higher modulation used for individual OFDM subcarriers, which results in higher N_{cbps}, together with higher code rate affect both $\Theta_{MAC\ net}$ and $\Theta_{OFDM\ symbol}$. Therefore we propose to evaluate the MAC layer efficiency as the ratio of OFDM symbols used for payload transmission in a frame to the total number of OFDM symbols in a frame. Letter L in the following equation always means length expressed as a number of OFDM symbols.

$$\eta = \frac{L_{net\ payload}}{L_{frame}} \quad (6)$$

The number of symbols in a frame does not depend on the modulation nor coding, as defined by equation 7.

$$L_{frame} = \left\lfloor \frac{T_{frame}}{T_{symbol}} \right\rfloor \quad (7)$$

A. MAC Efficiency in PMP Topology

In this section the MAC layer efficiency of the PMP topology is assessed. Our goal is to express the $L_{net\ payload}$ value. The uplink sub-frame consists of symbols used for ranging (L_{RNG}) and bandwidth requests (L_{BW}) and then of symbols containing UL physical layer PDUs. The length of the frame in OFDM symbols, when assuming one UL PHY PDU per subscriber station, can be written as:

$$\begin{aligned} L_{frame} &= L_{DL\ subframe} + L_{UL\ subframe} = \\ &= L_{DL\ PHY\ PDU} + L_{RNG} + L_{BW} + \sum_{i=1}^{N_{SS}} L_{UL\ PHY\ PDU\ i} \end{aligned} \quad (8)$$

1) Downlink Subframe

The DL sub-frame contains only one DL PHY PDU, which consists of the two-symbol long preamble and one-symbol Frame Control Header (FCH), then followed by the DL bursts. The DL burst #1 is different from other DL bursts (if present), since it contains broadcast MAC messages.

These broadcast messages comprise DL-MAP, UL-MAP, DCD and UCD messages. Their presence means less space for payload transmission, which means that longer broadcast messages decrease the MAC layer efficiency. The overhead in bytes introduced by them when assuming that all of them are present in the frame is given by equation 9.

$$OH_{DL\ burst\ \#1} = OH_{DL-MAP} + OH_{UL-MAP} + OH_{DCD} + OH_{UCD} + 4\cdot OH_{MAC\ PDU} \quad (9)$$

For our purposes it is necessary to express the length of the overhead in DL burst #1 in OFDM symbols, which can be done by using equation 10, where BpS is the number of uncoded bytes per OFDM symbol, as specified by equation 5.

$$L_{DL\ burst\ \#1} = \frac{OH_{DL\ burst\ \#1}}{BpS} \quad (10)$$

The resulting number of bytes available for transmission of data MAC PDUs can be calculated using equation 11.

$$L_{DL\ data} = L_{DL\ subframe} - L_{LP} - L_{FCH} - L_{DL\ burst\ \#1} \quad (11)$$

L_{LP} (long preamble) is 2 symbols and L_{FCH} is 1 symbol.

2) DL-MAP MAC Management Message

The DL-MAP message defines the access to the downlink information. It is a fixed part that is created by 8 bytes at the beginning. After this fixed part, several information elements (IEs) defining the fifth and further DL bursts are present.

The first four DL burst are specified in the DLFP burst. Another IE is at the end of the DL-MAP message, the DL-MAP end IE. Each of these IEs is 4 bytes long. The overhead in bytes introduced by the DL-MAP message is described by equation 9.1. $N_{DL\ burst}$ is the number of downlink bursts in the frame.

$$OH_{DL-MAP} = 8 + 4 \cdot \left(N_{DL\ burst} - 3 \right) \tag{9.1}$$

3) UL-MAP MAC Management Message

The UL-MAP message allocates access to the uplink channel. The length of the fixed part is for this message 7 bytes. The following IEs are 6 bytes long. One IE is used for every UL burst, i.e. for every subscriber station. The resulting overhead in bytes can be found in equation 9.2. N_{SS} is the number of transmitting subscriber stations.

$$OH_{UL-MAP} = 7 + 6 \cdot \left(N_{SS} + 2 \right) \tag{9.2}$$

4) DCD MAC Management Message

The DCD message is transmitted periodically by the MBS to define the characteristics of a downlink physical channel. Three bytes construct the fixed part of the message, the rest of the message is formed by the TLV tuples. Numerous TLV encodings are defined to describe the downlink channel properties and the burst profiles. Each burst profile definition occupies 9 bytes.

The resulting overhead caused by the DCD message is defined by equation 9.3. $N_{DL\ burst\ profiles}$ represents the number of downlink burst profiles used.

$$OH_{DCD} = 68 + 9 \cdot N_{DL\ burst\ profiles} \tag{9.3}$$

5) UCD MAC Management Message

The UCD message is similar to the DCD, but it describes the uplink physical channel. The fixed part comprises 6 bytes. TLV part without definition of burst profiles is 32 bytes long and each burst profile used occupies additional 12 bytes [1]. The UCD overhead can be evaluated as in equation 9.4. $N_{UL\ burst\ profiles}$ represents the number of uplink burst profiles used.

$$OH_{UCD} = 38 + 12 \cdot N_{DL\ burst\ profiles} \tag{9.4}$$

6) Uplink sub-frame

The uplink sub-frame contains slots for ranging, which are mainly used during the initial network entry or re-entry during handover. The number of bytes used for bandwidth requests can be calculated according to equation 12. N_{SS} is the number of subscriber stations. We assume that every SS sends one BW request every frame.

$$OH_{BW} = N_{SS} \cdot OH_{MAC\ PDU} \tag{12}$$

Expressed in OFDM symbols, equation 12 can be written as:

$$L_{BW} = \frac{N_{SS} \cdot OH_{MAC\ PDU}}{BpS} \tag{13}$$

We obtain the resulting number of OFDM symbols available for transmission of data MAC PDUs from the following equation.

$$L_{UL\ data} = L_{UL\ subframe} - L_{BW} - N_{SS} \cdot L_{SP} \tag{14}$$

B. Total Efficiency

Using equations 8, 11 and 14 it is possible to obtain the total number of OFDM symbols available for MAC PDUs as given by equation 15.

$$L_{data} = L_{frame} - L_{LP} - L_{FCH} - L_{DL\ burst\ \#1} - L_{BW} - N_{SS} \cdot L_{SP} \tag{15}$$

Another important overhead introduced by the MAC layer are the generic MAC headers and CRCs of the data PDUs. We suppose that the frame is fully used, the number of MAC PDUs which without considering fragmentation fit into one frame is given by equation 16, where *k* is the length including the generic MAC header and CRC of the MAC PDU in bytes. Applicable lengths are from 11 bytes (1 byte of payload) to 2047 bytes. The maximum length is restricted by the capacity of the Length field of the generic MAC header, which is 11 bits.

$$N_{MAC\ PDU} = \left\lfloor \frac{L_{data}}{k} \right\rfloor \tag{16}$$

Using the number of MAC PDUs in a frame, the number of OFDM symbols utilized for the data MAC PDUs overhead can be calculated, as given by equation 17.

$$L_{data\ MAC\ PDU\ OH} = \frac{N_{MAC\ PDU} \cdot 10}{BpS} \tag{17}$$

The number of OFDM symbols usable for the payload of the data MAC PDUs – SDUs from higher layers is given by equation 18.

$$L_{net\ payload} = L_{data} - L_{data\ MAC\ PDU\ OH} \tag{18}$$

Using the equation 6, efficiency on the MAC layer can be finally calculated. Results for various parameters will be presented in the next section.

IV. RESULTS IN MAC EFFICIENCY

The numerical values of the OFDM parameters, which are used to obtain the resulting efficiencies and haven't been presented before, are T_{frame} and T_{symbol}. T_{frame} defined by the standard IEEE802.16e-2005 [2], can have values from 2.5 ms to 20 ms. The third highest value, T_{frame} = 10 ms, is chosen for the calculations. T_{symbol} can be calculated using equation 19, with substituting the following: G = 1/4, BW = 20 MHz and n = 144/125. These values are allowed by the standard for license-exempt bands. Bandwidth of 20 MHz and the ratio of the cyclic prefix to the useful symbol time are both the largest allowed. The final symbol duration is then 13.89 µs.

$$T_s = T_b + T_g = (1/\Delta f) + G \cdot T_b = (1/\Delta f)\cdot(1+G) = \\ = (N_{FFT}/F_s)\cdot(1+G) = \left[N_{FFT} / (\lfloor n \cdot BW / 8000 \rfloor \cdot 8000) \right] \cdot (1+G) \quad (19)$$

Besides the main parameter, which is the number of subscriber stations (N_{ss}), other variables are chosen for the evaluated efficiency. These are the length of the data MAC PDUs, modulation/coding used, and number of burst profiles.

A. MAC PDU length

The length of the data MAC PDUs plays an important role for the efficiency value. The shorter the PDU is, the bigger part of it is occupied by the generic MAC header and CRC bytes, which for lower lengths significantly decreases the efficiency. The modulation QPSK 1/2 is assumed in the simulation. 1 DL burst profile and 1 UL burst profile is also considered.

In Figure 3, results for different number of subscriber stations (N_{ss}) are shown. It can be seen that the efficiency rises rapidly for smaller k values (approx. up to 100 bytes). After this point, the efficiency increases only gradually and for k values of 1000 bytes and more it is almost constant. At the same time it can be seen that for a certain MAC PDU length the largest number of subscriber stations has the lowest efficiency.

For higher number of subscriber stations, it obviously comes into effect for a lower initial PDU length. Nevertheless, the higher number of subscriber stations means lower efficiency.

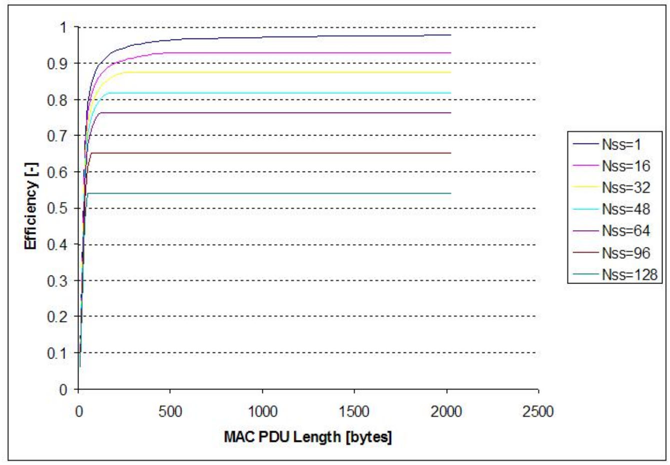

Fig.3. PMP efficiency – Paramater PDU length, parameter N_{ss}

B. Various modulation and coding

The influence of modulation and coding is presented when using 1 DL burst profile, 1 UL burst profile and fixing the MAC PDU length to 1024 bytes. When assuming this length or higher, the influence of the number of subscriber stations is much more noticeable than the influence of the PDU length.

Based on table 1, the efficiencies are calculated for six most common modulations/coding of them, omitting only the most robust BPSK 1/2 modulation. The modulation/coding types are numbered as in table 1.

Figure 4 shows that higher modulations usage means lower MAC overhead. That is due to the fact that the PMP broadcast messages don't have to be transmitted by the most robust modulation/coding. When a modulation/coding with a higher,

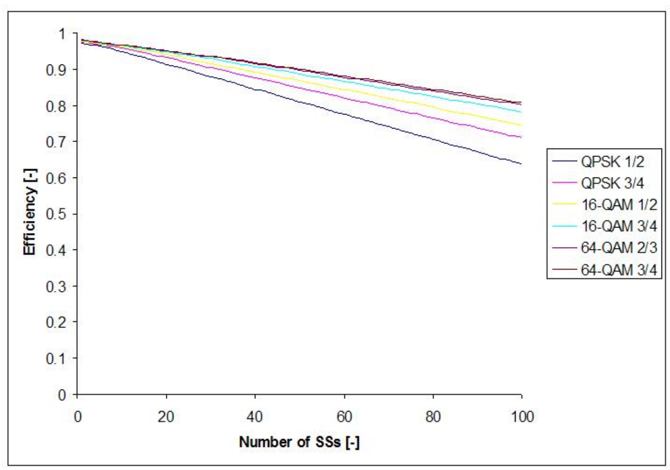

Fig.4. PMP efficiency – various modulations/coding, parameter modulation type

number of bytes per symbol is used the messages occupy a smaller portion of the PMP frame. For a higher number of subscriber stations the difference in efficiency for different modulations increases, because the more SSs are connected, the more OFDM symbols are used to send them and the more is consequently saved.

It is obvious that lower modulations mean lower efficiency variations when assuming different number of subscriber stations. The higher modulation is able to keep the efficiency high. That is caused by the fact that higher modulations slightly compensate the influence of growing broadcast messages.

C. *Various number of burst profiles*

Another parameter, which affects performance on the MAC layer, is the number of burst profiles (BP). We assume that the MAC PDU length is 1024 bytes and more uplink and downlink burst profiles are specified. For UL/DL burst profile 1 modulation/coding 1 is used, for UL/DL burst profile 2 modulation/coding 2 is used, etc. Maximum number of burst profiles is 6, since 6 most common modulations are used.

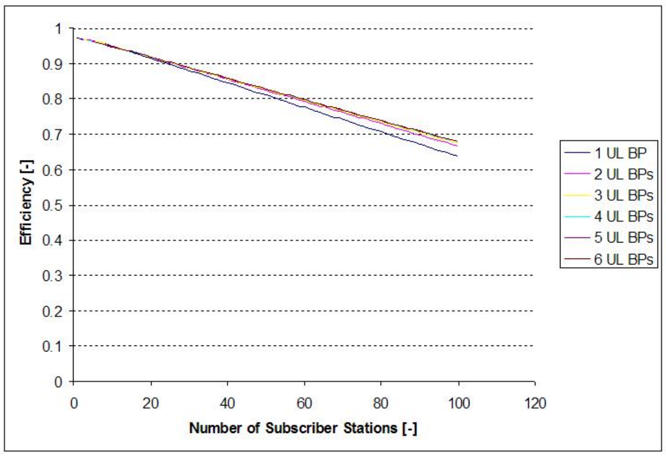

Fig.5. PMP efficiency – various number of N_{ss}, parameter BPs

Since the broadcast messages are assumed to be always transmitted using QPSK 1/2 modulation, using more burst profiles has only the influence of decreasing the efficiency because of additional overhead to define these BPs. This extra overhead is relatively small (approx. 6% between 1 BP and 6 BPs).

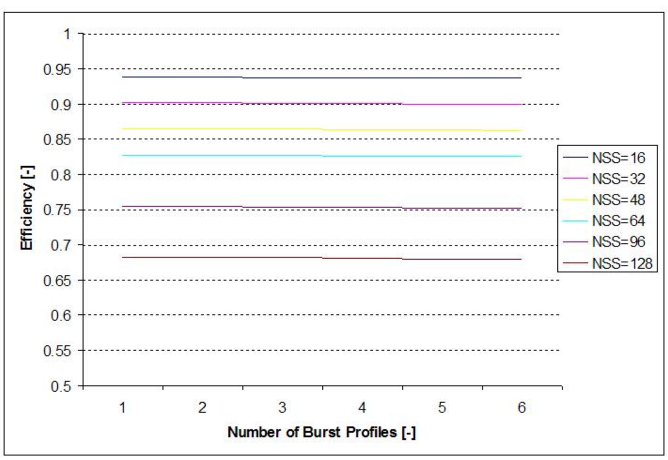

Fig.6. PMP efficiency – various number of burst profiles, parameter NSS

Figure 5 shows that the lower number of burst profile gives the lowest efficiency when N_{ss} is higher. On the other hand, Figure 6 depicts the fact that the BPs has a minor impact on MAC efficiency for particular number of subscriber stations. When the network has a lower number of subscriber stations then they will have a better efficiency.

V. CONCLUSIONS

Performance on the MAC layer of the IEEE 802.16 WirelessMAN standard has been analyzed. The Point to Multipoint mode is well suited for higher number of subscriber stations. Using the QPSK 1/2 modulation and MAC PDU length of 1024 bytes, the efficiency on the MAC layer is for 100 subscriber stations connected to the base station around 75%.

The data MAC PDU length is the parameter that highly influences the MAC layer performance. Obviously longer PDUs mean less MAC overhead. Another way of reducing the MAC overhead is usage of a higher modulation/coding. Especially for the PMP mode, transmitting the broadcast message with higher number of bytes per symbols gives more space to the data MAC PDUs transmission.

Introducing some changes to the IEEE 802.16 standard, for example defining more space saving TLV tuples for some of the management MAC messages could also bring some minor savings, but as the standard already experienced a gradual evolution and being implemented in many real-life applications, it doesn't make any sense to call for its change.

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