PROC_09_IEEE80216 MAC_IEEE-MICC 2009

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WORD COUNT 4121
TIME SUBMITTED 29-MAR-2021 02:43PM
PAPER ID 70475231

Proceedings of the 2009 IEEE 9th Malaysia International Conference on Communications
15 -17 December 2009 Kuala Lumpur Malaysia

IEEE802.16 MAC Management Messages: The Overhead and Efficiency Analysis in Mesh Topology

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***Abstract*— This paper presents the analysis of MAC Layer (L2) in wireless broadband system based on WiMAX IEEE802.16. The analysis is focused on overhead and efficiency of MAC Management Message and derived for mesh topology. The Mesh topology is evaluated concerning both existing types of scheduling – centralized and distributed – and their performance is compared. Some parameters, which deduced to have considerable influences i.e. the number of subscriber stations in the network, number of hops, various modulation and coding, and length of MAC PDUs, are assigned as the overhead parameters. The results show those parameters have significant impact on the efficiency of MAC layer.**

***Keywords*— IEEE802.16e, WiMAX, broadband wireless, MAC messages, MAC overhead, mesh network**

I. Introduction

The Worldwide Inter-operability for Microwave Access (WiMAX) is an emerging telecommunication technology based on IEEE802.16 standard [1]. WiMAX network, especially the mobile WiMAX which is based on IEEE802.16e, overcomes some limitations on 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) or Mobile Station (MS). Mesh topology, on the other hand, does not limit the link connection between BS-SS/MS only, but also support the connection among SSs/MSs. The SS/MS which have relay capability may be act as Relay Station (RS). A connection, used for the purpose of transporting Medium Access Control (MAC) management message is required by the MAC layer.

The overhead caused by transporting the MAC messages throughout the network is an important performance indicator, because it significantly influences the system 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.

Many papers evaluated MAC performance of wireless system. Most of them are based on the WiFi IEEE 802.11 standard. In [3] the authors study the influence of MAC overhead when analysing the stale cache problem in IEEE 802.11 ad-hoc networks with on-demand routing protocol. The MAC overhead can degrade performance significantly. In [4] the authors investigated MAC performance of the amendment of 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. They concluded that MAC overhead affected the system throughput by reducing the bit rate and increase the delay.

The authors in [5] analyze the MAC efficiency dedicated to multi-hop wireless networks based on IEEE 802.16a standard. 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. We adopted some mechanisms in [5] on our previous works. In [6] [7], we analysed the MAC efficiency of IEEE802.16d on PMP topology. Some MAC messages were examined. Several overhead parameters were used to analyse their impact on system performance.

The focus of this paper is the efficiency analysis of MAC management messages transferred in mesh topology in both centralised and distributed scheduling. We consider the basic IEEE802.16's MAC messages that involve in network admission process and some overhead parameters i.e. number of SSs in the network, number of hops, various modulation and coding schemes, and length of MAC protocol data unit (MAC PDU) of the message.

The organisation of this paper is as follows. In section II, the IEEE802.16 layer model mainly for the Mesh 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. Section IV shows the analysis results of message overhead and its efficiency. We also discussed the simulation results. Section V provides our conclusions and recommendations.

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II. THE LAYER MODEL OF WIMAX IEEE802.16

A. The Functionality of IEEE802.16 MAC Layer

The IEEE802.16 MAC layer reference consists of three sub-layers model as shown in Fig. 1 [8][9].

The Service-Specific Convergence Sub-layer 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 is not required to parse any information from the Convergence Sub-layer 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.

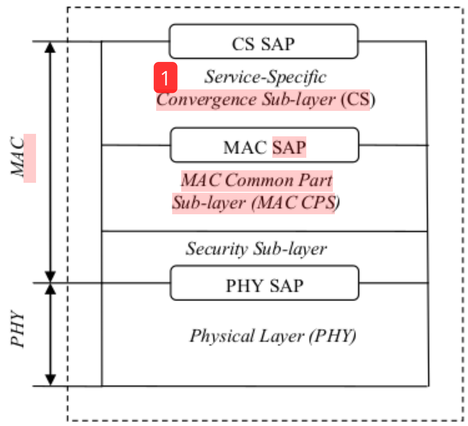


Fig. 1. IEEE 802.16 – layer model – data/control plane

In IEEE 802.16e, total 64 MAC management messages are defined. The standard also defined there types of connection for each messages i.e. *broadcast*, *basic management* and *primary management*. The complete list can be found in [2]. These messages are carried in the payload of the MAC PDU. They begin with a type field and contain additional fields. The structure of MAC management message is depicted in Fig. 2.

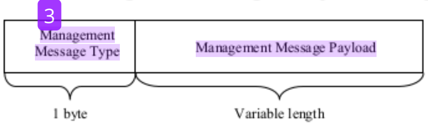


Fig. 2. MAC management message structure

The payload structure of MAC management messages is specified by the standard separately for each message. The payload of the most common messages can be divided into two parts. The first one is a fixed part and the second part is created by type-length-value tuples (TLV part).

B. Mesh Topology in IEEE802.16

In mesh topology, the traffic can be routed through other SSs and can occur between SSs. This can be done on the basis of equality using distributed scheduling, or using a mesh BS as the superior (centralized scheduling), or combination of both.

A mesh BS is a system with direct connection to backhaul services outside the mesh network. Uplink (UL) is defined as traffic in the direction of the mesh BS and downlink (DL) as traffic away from mesh BS. The stations in which a node has direct links are called neighbours and form a (one-hop) neighbourhood. An extended neighbourhood contains all the neighbours of the neighbourhood. An example constellation of mesh SSs with a mesh BS, where neighbourhood and extended neighbourhood of mesh SS 1 are shown, is depicted in Fig. 3.

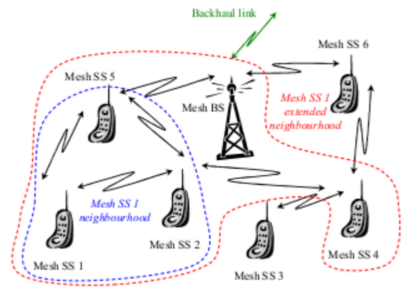


Fig. 3. Example of mesh topology based on IEEE802.16

Unlike the PMP mode, in mesh topology there are no clearly separate downlink and uplink sub-frames. Each station is able to create direct communication links to several other stations instead of communicating only with the BS. The method of requesting bandwidth is dependent on the scheduling type selected.

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.

TABLE I
MANDATORY CHANNEL CODING/MODULATION

Modulation	Uncoded block size (bytes)	Coded block size (bytes)	Overal coding rate
BPSK	12	24	½
QPSK	24	48	½
QPSK	36	48	¾
16-QAM	48	96	½
16-QAM	72	96	¾
64-QAM	96	144	2/3
64-QAM	108	144	¾

III. The Efficiency of MAC Message

A. MAC Overhead and Efficiency

The MAC overhead can be evaluated by means of determining the efficiency of the MAC layer. According to [5][6][7] the MAC efficiency can be defined as the ratio of the net throughput on MAC layer and the throughput per OFDM symbol as shown in Eq. (1).

$$\eta = \frac{\Theta_{MAC\ net}}{\Theta_{OFDM\ symbol}} \tag{1}$$

The net throughput on the MAC layer is defined by Eq. (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}.

$$\Theta_{MAC\ net} = \frac{\sum Payload\ bits}{T_{frame}} \tag{2}$$

The throughput of an OFDM symbol can be calculated as:

$$\Theta_{OFDM\ symbol} = \frac{\left(N_{used} - N_{pilot}\right) \cdot N_{cbps} \cdot C}{T_{symbol}} \tag{3}$$

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.

The number of uncoded bytes per symbol is given as:

$$BpS = \frac{\left(N_{used} - N_{pilot}\right) \cdot N_{cbps} \cdot C}{8} \tag{4}$$

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 as given in Eq. (5). Letter L in the following equation always means length expressed as a number of OFDM symbols.

$$\eta = \frac{L_{net\ payload}}{L_{frame}} \tag{5}$$

The number of symbols in a frame does not depend on the modulation or coding, as defined by Eq. (6).

$$L_{frame} = \left\lfloor \frac{T_{frame}}{T_{symbol}} \right\rfloor \tag{6}$$

B. Evaluation in Mesh Topology

Network topologies using the mesh mode can be quite varying. The mesh SS may have direct links between each other and traffic for other mesh SSs can be routed across these links. There are innumerable possibilities how the topology can look like.

Since the purpose of this paper is to evaluate the MAC overhead, a particular topological model is needed. We propose using a tree topology. Each node in the tree, except of the last level of nodes, which have the highest hop count from the root node, has $\boldsymbol{a}$ children. The number of hops from the root node to another node is marked as $\boldsymbol{h}$. The maximum number of hops is designated $\boldsymbol{h_{max}}$. Fig. 4 shows the proposed tree topology.

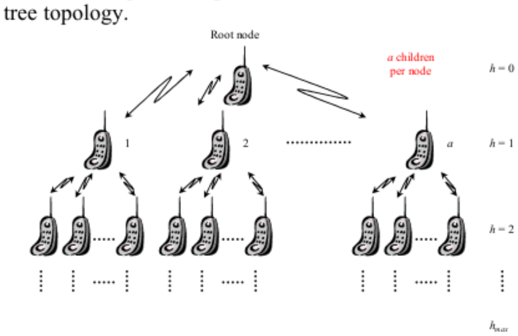


Fig. 4. Proposed Tree-like topology

Subsequently, based on the topology proposed, we need to make a traffic assumption. Let's define that only the root node (using centralized scheduling terminology – the mesh BS) is connected to the core network and the end-to-end connections occurs between the mesh SSs and some unspecified nodes outside this network and not between individual mesh SSs. It means that data for nodes in the lower parts of the tree is routed through SSs on higher levels.

The mesh frame of the message doesn't have clearly separated downlink and uplink, however it consists of the control sub-frame and the data sub-frame. The Schedule control sub-frame contains distributed and centralized scheduling messages.

1) Centralised Scheduling(CS)

The length of the control sub-frame using CS in OFDM symbols depends on the number and length of CS bursts. It has to be a multiple of 7 OFDM symbols [1][2]. The length of control sub-frame is given in Eq. (7).

$$L_{control\ subframe} = 7 \cdot \left\lceil \frac{a \cdot L_{CSCH}}{7} \right\rceil \tag{7}$$

We assume that requests are collected from the lower levels and passed on to the mesh BS (refer to Fig. 4). Then the mesh BS responds with the appropriate grants. The intermediate mesh SSs take their part of the grants and forward the rest down the tree. The requests and grants messages appear in equal quantity.

The number of request bursts in a frame is equal to the number of children per node, i.e. $\boldsymbol{a}$. Number of bursts doesn't depend on the hop count $\boldsymbol{h}$ from the root node, but their size does. The same stands for the number of the grant bursts. There are always $\boldsymbol{a}$ grants, one for each of node's children.

Thus, a frame contains either ***a*** bursts with requests from the children or ***a*** bursts containing grants for them.

The mesh CS message, MSH-CSCH, is used by the mesh BS to broadcast the centralized schedule. All nodes with hop count lower than specified have to forward this message to their neighbours with a higher hop count. In the calculation we assume that the maximum hop count for forwarding is the same as the h_{max} parameter.

It is also used by the mesh SSs to request bandwidth from the mesh BS. The nodes report individual traffic demand requests of each child node further from the mesh BS, as well.

The message has a fixed part which in total has 4 bytes. The information carried by this part includes e.g. *Message Type, Grant/Request Flag,* and *Configuration Sequence Number* or *NumFlowEntries* fields. The *Grant/Request Flag* indicates whether MSH-CSCH serves as a grant or a request, *Configuration Sequence Number* refers to the configuration number in the MSH-CSCF message. *NumFlowEntries* specifies the number of flow entries which describe individual demands of the nodes lower in the routing tree. *NumFlowEntries* in Eq. (8) is labelled as N_{flow}. It can be calculated as:

$$N_{flow}(h) = \sum_{i=0}^{h_{max}-h} a^i \qquad (8)$$

$N_{flow}(h)$ expresses the number of lower nodes which are found on a branch under node on level h – 1. The parameter h means that the number of flow entries is calculated for a link with position h from the root.

As the requests and grants appear in the same ratio, so the corresponding overhead of MSH-CSCH: Request and MSH-CSCH: Grant messages are evaluated in Eq. (9).

$$OH_{MSH-CSCH} = 5 + \frac{3}{4} N_{flow} \qquad (9)$$

2) Distributed Scheduling(DS)

In this paper we concern only coordinated-DS. The uncoordinated type is mainly suitable for fast link setups, which isn't the case selected by us. Using the DS, the length of the control sub-frame can be written as in Eq. (10). There is a difference in the number of scheduling bursts in a frame. We assume that the chosen node transmits one scheduling burst of length $L_{DSCH\ high}$ and every child node transmits one scheduling burst of length $L_{DSCH\ low}$.

$$L_{control\ subframe} = 7 \cdot \left\lceil \frac{a \cdot L_{DSCH\ low} + L_{DSCH\ high}}{7} \right\rceil \qquad (10)$$

The lengths of a DS burst $L_{DSCH\ low}$ and $L_{DSCH\ high}$ can be calculated using Eq. (11).

$$L_{DSCH} = \left\lceil \frac{OH_{MSH-DSCH} + OH_{MAC\ PDU\ Mesh}}{BpS_{QPSK1/2}} \right\rceil + L_{LP} + L_{guard} \qquad (11)$$

These two lengths differ from each other only because of different number of neighbours. Each burst consists of the mesh DS message, MSH-DSCH, which has the long preamble (L_{LP}) and one guard symbol (L_{guard}). It is again transmitted using the QPSK 1/2 modulation/coding, which means 24 uncoded bytes per OFDM symbol.

The MSH-DSCH, carried in the DS bursts, is transmitted at a regular interval to inform all the neighbours of the schedule of the transmitting station. It is used to convey resource requests (MSH-DSCH: Request) and grants (MSH-DSCH: Grant) to the neighbours and also to inform the neighbours about available free resources (MSH-DSCH: Availability) that can be used to send grants. The average overhead introduced by MSH-DSCH messages is defined by Eq. (12) as follow:

$$OH_{MSH-DSCH} = 6 + 3 \cdot (N_{neigh} + 1) + 4\frac{1}{8} \cdot (N_{ext\ neigh} + 1) \qquad (12)$$

3) Total Efficiency

Using all pevious equations, it is possible to obtain the total number of OFDM symbols available for MAC PDUs as given by Eq. (13).

$$L_{data} = L_{frame} - L_{LP} - L_{FCH} - L_{DL\ burst\ \#1} - L_{BW} - N_{SS} \cdot L_{SP} \qquad (13)$$

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 Eq. (14), 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.

$$N_{MAC\ PDU} = \left\lfloor \frac{L_{data}}{k} \right\rfloor \qquad (14)$$

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 Eq. (15).

$$L_{data\ MAC\ PDU\ OH} = \frac{N_{MAC\ PDU} \cdot 10}{BpS} \qquad (15)$$

The number of OFDM symbols usable for the payload of the data MAC PDUs – SDUs from higher layers is given by Eq. (16).

$$L_{net\ payload} = L_{data} - L_{data\ MAC\ PDU\ OH} \qquad (16)$$

Using the Eq. (5), efficiency on the MAC layer can be finally calculated. Results for various parameters will be presented in the next section.

IV. Results and Discussion

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 other 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.

T_{frame} defined by the standard [1] can have values from 2.5 ms to 20 ms. The third highest value, T_{frame} = 10 ms, was chosen for the calculations. T_{symbol} can be calculated using Eq. (1) 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 that have been allowed. The final symbol duration is then 13.89 µs.

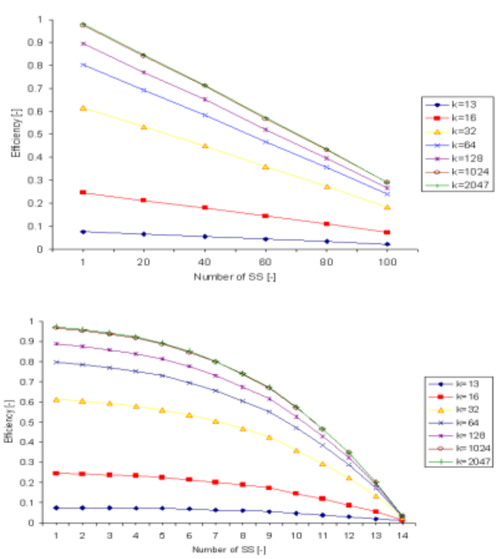


Fig. 5. MAC message efficiency in mesh, CS (top) and DS (bottom), various PDU lengths (***k*** parameter).

. First, let's discuss the results for the shortest and longest MAC PDUs allowed and for several lengths in between, as shown in Fig. 5. It can be seen that both CS (top) and DS (bottom) have a quite similar characteristics since the efficiency is decrease when the length of PDU is decreased.

For CS, the efficiency decrease linearly, however, overhead per SS is much higher. When assuming e.g. 100 SSs, the MAC layer efficiency is only around 0.3. On the other hand, the DS can support only up to 14 SSs with the efficiency lower than CS. It is caused by the fact that all SSs are members of one extended neighbourhood and have to coordinate their transmission with each other, using the MAC management messages.

Next results discussion, as shown in Fig. 6, are about the MAC efficiency where the CS (top) and DS (bottom) also have similar characteristics when modulations too part as the overhead parameter. For CS, since the control sub-frame of the mesh frame is defined to always use QPSK 1/2 modulation/coding, only the data sub-frame can be transmitted with different modulation/coding setting. Higher modulation enables more MAC PDUs to fit into one frame.

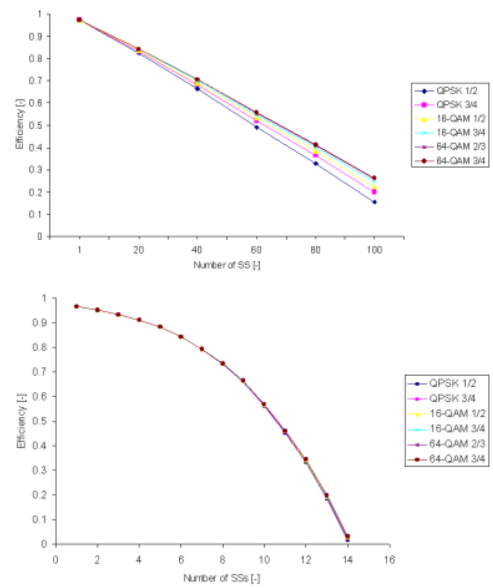
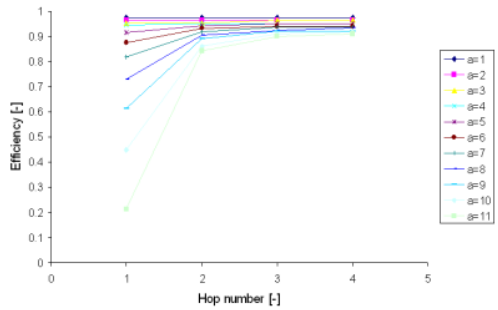


Fig. 6. MAC message efficiency in mesh, CS (top) and DS (bottom), various modulations (***modulation*** parameter).

However, the efficiency remains the same, because the ratio between the MAC PDU overhead and a given PDU length is constant, e.g. when assuming k = 1024 bytes, the efficiency stays the same for all possible modulations. In this analysis, the PDU length is shortened for higher number of SSs. For higher modulation, limiting the length for higher number of SSs give effect the lower efficiency.

Finally, the MAC efficiency on links corresponding to individual hops is depicted in Fig. 7. It is quite interesting why the efficiency is higher on links further from the root node (see figure on top). The reason is due to the fact that less request and grant messages are transmitted there. Unrestricted bandwidth allocation also affected to the high efficiency in low level of hops. Figure on the bottom depicts the opposite results when a restricted bandwidth is applied in lower level of hops. However, it is obviously confirmed that children (SSs) per node introduce notably higher overhead, which results in lower efficiency.



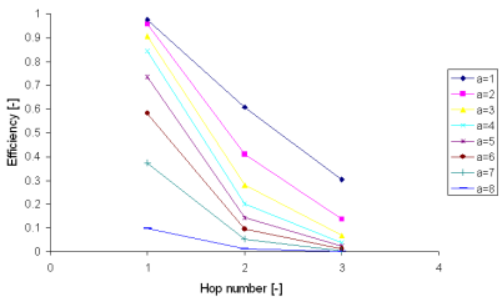


Fig. 7. MAC message efficiency in mesh, unrestricted bandwidth (top) and restricted bandwidth (bottom), various number of hops and node levels (***a*** and ***h*** parameters).

The last Fig. 8. shows the efficiency performance of MAC management message in PMP topology and Mesh topology in both CS and DS. When concerning different number of subscriber stations, the PMP mode is the most efficient than Mesh CS and Mesh DS (reader who interested in the result of PMP topology may found it in [6] and [7]).

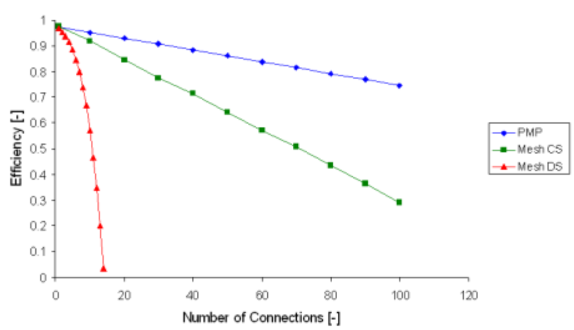


Fig. 8. The comparison of MAC efficiency between PMP topology and Mesh topology.

V. CONCLUSIONS

In this paper the analytical derivation of the IEEE 802.16 MAC management message overhead and efficiency in mesh topology was presented. The mesh mode is a good option when low number of SSs are employed and building a PMP network would be too complicated.

When considering the mesh mode the selection of the right scheduling method is also crucial. As it can be seen from the results, CS brings less overhead than the DS version. The DS showed lower efficiency when calculating the overhead for presented scenarios in comparison to the centralized one, but if the traffic takes place mainly between individual Mesh subscriber stations, the efficiency may be better.

The data MAC PDU length is another parameter that highly influences the MAC layer performance. Obviously longer PDUs mean less MAC overhead.

Transmitting the broadcast message with higher number of bytes per symbols creates more space for the data MAC PDUs transmission. Thus, the usage of higher modulation/coding, can reduce the MAC overhead.

ACKNOWLEDGMENT

This paper is part of research work that supported by the internal research grant of Czech Technical University in Prague. Interní grantová soutěž (IGS) ČVUT No. CTU0921213.

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