Efficient Coupled PHY and MAC use of Physical Bursts by ARQ-Enabled Connections in IEEE 802.16e/WiMAX Networks

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Abstract: In this paper we address an aspect of the mutual influence between the PHY layer budding blocks (FEC Blocks) and the MAC level allocations in the Uplink and Downlink of IEEE 802.16e/WiMAX networks. In these networks it is possible to transmit MAC level frames, denoted MAC PDUs, such that a PDU contains an integral number of fixed size Data Blocks. PDUs are transmitted over PHY Bursts, which are divided into FEC Blocks. We suggest an algorithm that computes the best way to define PDUs in a Burst in order to maximize the Burst Goodput. We also give guidelines on how to choose the best Modulation/Coding Scheme (MCS) to use in the Burst, given the SNR of the channel.

1 INTRODUCTION

Broadband Wireless Access (BWA) networks constitute one of the greatest challenges for the telecommunication industry in the near future. These networks fulfill the need for range, capacity, mobility and QoS support from wireless networks. IEEE 802.16e (IEEE, 2005), also known as WiMAX(Worldwide Interoperability for Microwave Access) is the industry name for the standards being developed for broadband access.

IEEE 802.16e is a cell based, Point-to-MultiPoint (PMP) technology, providing high throughput in Wireless Metropolitan Area networks (WMANs). The IEEE 802.16e standard reference model includes the Physical and Medium Access Control (MAC) layers of the OSI protocol stack. Multiple physical layers are supported, operating in the 2 to 66 GHz frequency spectrum and supporting single and multi-carrier air interfaces, each suited to a particular environment. For IEEE 802.16e to be able to fulfill the promise for high speed service, it must efficiently support advanced Modulation and Coding schemes (MCSs) and progressive scheduling and allocation techniques.

In this study we focus on the influence between the PHY layer budding blocks (FEC Blocks) and the length/location of the MAC layer frames denoted as *MAC PDUs*, in the Uplink and Downlink of IEEE 802.16e systems, assuming that Data Blocks are transmitted in the PDUs, as will be explained later.

1.1 The IEEE 802.16e/WiMAX Network Structure

IEEE 802.16e/WiMAX is a standard for a Broadband Wireless Access (BWA) network (IEEE, 2005) which enables home and business subscribers high speed wireless access to the Internet and to Public Switched Telephone Networks (PSTNs). The system is composed of a Base Station (BS) and subscribers, denoted as Mobile Stations (MSs), in a cellular architecture. The transmissions in a cell are usually Point-to-Multipoint, where the BS transmits to the subscribers on a Downlink channel and the subscribers transmit to the BS on an Uplink channel.

A common PHY layer used in IEEE 802.16e is Orthogonal Frequency Division Multiple Access (OFDMA) in which transmissions are carried in *transmission frames* (IEEE, 2005). Every frame is a matrix in which one dimension is a sub-channel (band of frequencies) and the other dimension is time. A cell in the matrix is denoted as a *slot*. The number of data bits that can be transmitted in a slot is a function of the Modulation and Coding scheme (MCS) that is used in the slot.

A Burst in a frame is a subset of consecutive slots sharing the same MCS, which is designated to a sub-

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set of MSs for their transmissions. In the most common case a Burst is designated to a single MS, and this is the case that we consider in this paper. In this paper we assume that the Convolutional Turbo Code (CTC) is used as the coding scheme, and in this case a Burst also maps *Forward Error Correction (FEC) Blocks* to the slots. In this paper knowing the details behind the FEC technology is unnecessary so we will not elaborate on this subject. The only property needed is that all the data bits in a FEC Block have some probability p to arrive successfully at the receiver.

1.2 Transmissions in IEEE 802.16e Systems

The BS and the MSs transmit *Protocol Data Units* (PDU) within Bursts. The MAC layer of IEEE 802.16e is connection oriented and PDUs, which are the MAC level frames, thus belong to MAC connections (IEEE, 2005). Within PDUs the BS and the MSs transmit their application packets that are denoted *Service Data Units* (SDU). An SDU can be an IP packet, ATM cells, etc. The PDUs are used to map SDUs into the MAC connections, to protect the SDUs from transmission errors, to enable encryption of the SDUs, etc. Each PDU has a fixed header, denoted Generic MAC Header (GMH). This header is mainly used to associate a PDU to a MAC connection. Optionally, a PDU also has a CRC field. Any of the other aforementioned functions performed on the PDU payload requires an additional subheader. All the (sub)headers within a PDU are considered to be *PDU overhead*.

Let p be the probability that all the bits of a FEC Block, after decoding, arrive correctly at the receiver. This probability is a function of several parameters such as the Coding rate, the number of decoding iterations in the case of Turbo codes (Huang, 1997), the Signal-to-Noise Ratio (SNR) of the channel and the length, in bits, of the FEC Block (Huang, 1997). p is bigger for longer FEC Blocks. In this paper, based on (Alpert et al., 2013), we assume that all the FEC Blocks are of the same size and that p is similar for all the FEC Blocks of a transmission frame, i.e. there is no correlation dependency between the success probabilities of FEC Blocks of the same size in a transmission frame.

The probability Q that a PDU arrives correctly at the receiver is the probability that all its bits arrive correctly. This is also the probability that all the FEC Blocks that contain a part of the PDU arrive correctly.[1] Thus, in view of the above assumption on p, if a PDU is transmitted within X FEC Blocks, holds $Q = p^X$.

In this paper we concentrate on one type of MAC connections, *ARQ-enabled* connections. In such connections the SDUs are divided into Blocks, denoted *Data Blocks*, of the same size. This size is defined at the time when a connection is established. In the case where the length of an SDU is not an integral number of the Data Block size, the last Data Block of the SDU is shorter, but it is not padded.

The purpose of the division into Data Blocks is to enable the transmitter to know whether the SDUs it transmits arrive successfully at the receiver. This is accomplished by ARQ Feed-backs that are transmitted back from the receiver to the transmitter. The receiver notifies the transmitter about every Data Block whether it arrived successfully or not. In the case where a Data Block is not received successfully, it is retransmitted by the transmitter. The only correctness check that a receiver is performing is in the PDU level. Thus, the receiver considers all the Data Blocks in a PDU as either arriving correctly or not.

In this paper we focus on the following question: Given the Signal-to-Noise Ratio (SNR) of the channel, a Burst and a MCS, which determines the size and number of FEC Blocks in the Burst, and the success probability of a FEC Block, what is the most efficient way to transmit PDUs in the Burst so that the Burst Goodput is maximized. We then suggest another performance criteria which counts the number of Data Blocks that are transmitted successfully in a Burst. Finally, we give guidelines on how to choose the MCS to use in the Burst according to the two performance criteria. All that is described in Section 2. As far as we know, the problem considered in this paper has not been investigated before.

There are many papers that deal with the efficiency of WiMAX networks. Due to space limits we only include in the References section the papers that we use directly in the current paper.

[1] This is actually an approximation. It can happen that the bits of a FEC Block that are contained in a PDU arrive correctly, and thus also the PDU, while other bits of the FEC Block arrive damaged. However, we use this approximation following the WiMAX radio performance testing (WiMAX, 2008). In this testing it was found that the bursty nature of errors in the air IF, and the operation of the interleaver in CTC codes, tend to disperse the bit errors (after decoding) over the FEC Block, so that there is usually more than a single error, and the errors would be distant from one another. The result is that all the PDUs, with bits in a FEC block, would most likely suffer.

2 MAXIMIZING THE BURST'S GOODPUT

2.1 Problem Description

We are given an SNR, a Burst of S slots, an infinite set of Data Blocks of length B bits each and the number of PDU overhead bits. The problem that we want to solve is as follows: Given a Modulation/Coding Scheme (MCS), how to divide the Burst into PDUs such that the Burst Goodput is maximized. The given MCS determines the number and the length of the FEC Blocks in the Burst, and their success probability.

2.2 Definition of the Burst's Goodput

We are given:

1. A Burst of L FEC Blocks
2. Every FEC Block contains F bits
3. Every FEC Block has probability p to arrive successfully at the receiver
4. An infinite number of Data Blocks. Each has a length of B bits.
5. Every PDU has O overhead bits. We assume that $O < F$ since according to the IEEE 802.16e/WiMAX standard (IEEE, 2005) the total length of the overhead fields in a PDU is most likely to be smaller than one FEC Block.

We want to transmit as many Data Blocks as possible in the Burst such that the *Burst Goodput (B-Goodput)* is maximized. The *B-Goodput* is defined as follows: Let D be the number of Data bits that are transmitted successfully in the Burst. Then, *B-Goodput*= $\frac{D}{L \cdot F}$. D is computed as follows: Assume that a PDU is defined over k FEC Blocks. Then, the success probability of the PDU is p^k and every Data Block in the PDU contributes $B \cdot p^k$ bits to D. D is the summation of the contributions of all the Data Blocks in the Burst.

2.3 Characteristics of the Optimal Location of PDUs

Since Data Blocks are transmitted in PDUs, we need to decide on how many PDUs shall be allocated in the Burst, their length and their location. We call these decisions the *division* of the Burst into PDUs.

In principle a PDU can start at any bit position within a FEC Block. We design a dynamic programming algorithm that checks all these possibilities within a FEC Block. However, for the case where $2B-1 < F$ we show that a PDU can begin only at the first B bits of a FEC Block, or at the last $B-1$ bits of a FEC Block and thus the algorithm does not need to go over all the bit positions in a FEC Block.

Consider a Burst of L FEC Blocks as shown in Figure 1. We number the FEC Blocks in the Burst from right to left, such that the right most FEC Block is FEC Block 1 and the left most FEC Block is FEC Block L.

In view of the above, we divide the discussion into two cases, $2B-1 < F$ and $2B-1 \geq F$.

2.3.1 The Case $2B-1 < F$

Theorem 1. *There is an optimal division of the Burst in which the first PDU begins at the beginning of the left most FEC Block (left edge of the Burst in Figure 1) and every other PDU either begins immediately after the previous one (back to back) or at the beginning of the next FEC Block following the end of the previous PDU (towards the right edge of the Burst).*

Proof. Consider an optimal division S of the Burst. If S fulfills the Theorem then we are done. Otherwise, we show how to change S so that the new optimal division fulfills the Theorem. Notice that in general, if we move a PDU in the Burst towards the left edge of the Burst, then as long as the beginning of the PDU does not cross a FEC Block boundary, we either do not change the number of FEC Blocks over which the PDU is defined, or we decrement this number by one. If the PDU crosses a FEC Block boundary, then if it returns to the same position within a FEC Block as its original position, then the number of FEC Blocks over which it is defined is not changed. Therefore, if the first PDU in S is not allocated from the left edge of a Burst, one can move it to this location without increasing the *B-Goodput*. We now consider the second PDU in S, from the left, and move it an integral number of F bits until it reaches a point where there is at most one FEC Block boundary between its start position and the end of the first PDU. Now, the second PDU can be moved to reach the end of the first PDU, if it does not cross the boundary of a FEC Block, or otherwise to the beginning of the FEC Block immediately following the first PDU. By following this process for every PDU, one can generate a division that fulfills the Theorem. □

From now on we consider only divisions that fulfill Theorem 1. We also denote the first *(B-1)* bits in a FEC Block as the *Starting edge* of the FEC Block, and the last B bits as the *Ending edge*.

Theorem 2. *In an optimal division of a Burst, every PDU ends either within the Starting edge or within the Ending edge of a FEC Block.*

Proof. Consider an optimal division of the Burst. If all the PDUs end within the above edges of a FEC Block then we are done. Otherwise, let the k^{th} PDU from the left of the Burst, denoted PDU_k, to be the first PDU from the left that ends at a bit of a FEC Block which is outside the above edges. If PDU_{k+1} begins at the next FEC Block boundary, or in the case that PDU_k is the last PDU in the Burst, one can add at least one Data Block to the Burst, at the end of PDU_k, without changing the success probabilities of the existing PDUs, thus increasing the *B-Goodput* and contradicting the optimality of the given division.

Therefore, assume that PDU_{k+1} begins immediately after PDU_k. If the success probability of PDU_{k+1} is larger than that of PDU_k then one can move one Data Block from PDU_k to PDU_{k+1}, thus increasing the *B-Goodput*, contradicting the optimality of the given division. If the success probability of PDU_k is larger than that of PDU_{k+1} then again one can move one Data Block from PDU_{k+1} to PDU_k. The success probability of PDU_k is not changed. The success probability of PDU_{k+1} can only increase (we shorten PDU_{k+1}), and again the overall *B-Goodput* increases, contradicting the optimality of the given division.

It turns out that the success probabilities of PDU_k and PDU_{k+1} must be equal. One can now move Data Blocks from PDU_k to PDU_{k+1} until one of the following occurs: there are Data Blocks left in PDU_k but the movement of one more Data Block will cause the beginning of PDU_{k+1} to cross a FEC Block boundary, or there are no Data Blocks left in PDU_k. In the first case PDU_k ends within the Starting edge of a FEC Block. In the second case we can omit PDU_k from the division and move PDU_{k+1} to begin at either the beginning of a FEC Block or after PDU_{k-1}.

Repeating the above process ends with a division as claimed in the Theory. □

2.4 An Algorithm to Compute the *B-Goodput*

Theorems 1 and 2 establish the theoretic basis for a dynamic programming algorithm to find the optimal division of a Burst. We denote this algorithm by *Division-Find*. Algorithm *Division-Find* builds a table T of L rows, as the number of FEC Blocks in the Burst. The first row of T refers to FEC Block 1 of the Burst and so on. Row number k shows the optimal use of FEC Blocks 1 to k of the Burst, as it is explained in the following. Every row has $(2B-1)$ entries, corresponding to the places within a FEC Block where a PDU can *start*, following Theorem 2. These entries of row k are numbered $T[k,1], T[k,2], ..., T[k,B], T[k,F-(B-2)], ..., T[k,F]$.

The entries in T contain an average number of successfully transmitted data bits, and *not* Goodputs. The Goodput can be received by dividing the value in an entry by the Burst size. The entries are computed as follows. In row 1 we fill entries $T[1,1], ..., T[1,B]$ only. Entry $T[1,j], 1 \leq j \leq B$ is computed assuming that a PDU begins at bit number j in the FEC Block and it contains as many Data Blocks as possible. Say for entry $T[1,j]$ one can allocate a PDU of X FEC Blocks, starting from bit number j in the FEC Block. Then $T[1,j] = X \cdot B \cdot p$.

We now move to row $k, 2 \leq k \leq L-1$. In each of these rows we first compute entries $T[k,F-(B-2)], ..., T[k,F]$ and then entries $T[k,1], ..., T[k,B]$. We first handle row 2 and consider entries $T[2,j], F-(B-2) \leq j \leq F$. We want to find how the section of the Burst, starting from bit j of the second FEC Block, and ending at the end of the Burst, is most efficiently used, i.e. how one shall divide this section into PDUs such that the maximal average number of data bits are transmitted successfully. One needs to consider 3 cases, derived from Theorems 1 and 2, as shown in Figure 2, and choose the maximum among the 3. Notice that not all the cases in Figure 2 always exist. This depends on the relation between $O+B$ to F, e.g. if $O+B$ is larger than $2B-1$ in case B in Figure 2 then this case actually does not exist. Also notice that in cases B and C one uses entries from row 1.

We now move to entries $T[2,1], ..., T[2,B]$. Consider entry $T[2,j]$ in this set. We assume that a PDU begins at bit j of the FEC Block and consider all the possibilities to allocate PDUs at the section of the Burst that begins at bit j of the second FEC Block and that ends at the end of the Burst. We have 3 cases, as shown in Figure 3, again derived from Theorems 1 and 2. The value of $T[2,j]$ is the maximum among all the cases. Notice that in case C we use an entry in row 2 that was already computed, and in case B we use an entry in row 1. Again, not all the 3 cases always exist.

Concerning row L notice that at most two entries need to be computed. From Theorem 1 entry $T[L,1]$ must be computed. Also, let $X \geq 1$ be the largest integer such that $O + X \cdot B + 1 \leq F$. Then entry $T[L, O + X \cdot B + 1]$, if exists, must also be computed. As in the previous rows entry $T[L, O + X \cdot B + 1]$ is computed before entry $T[L,1]$ and notice that entry $T[L,1]$ is the result of the algorithm that we are looking for.

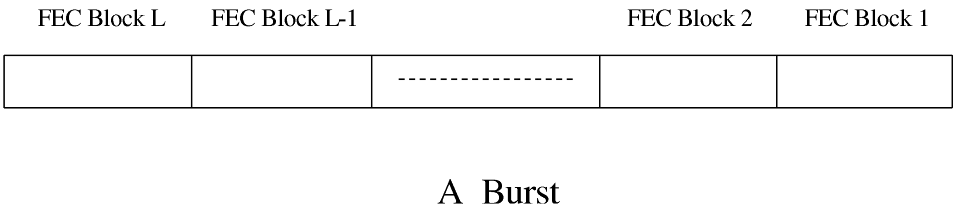

Figure 1: Numbering the FEC Blocks in a Burst.

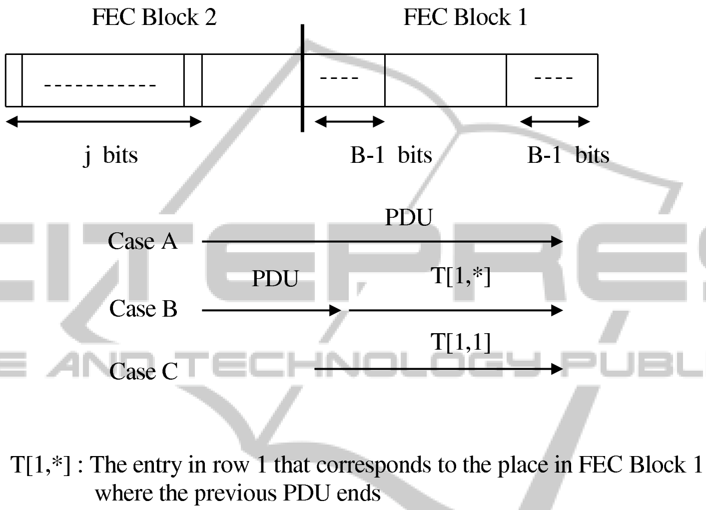

Figure 2: Computing entry $T[2,j], F-(B-2) \leq j \leq F$ in the table of algorithm *Division-Find*.

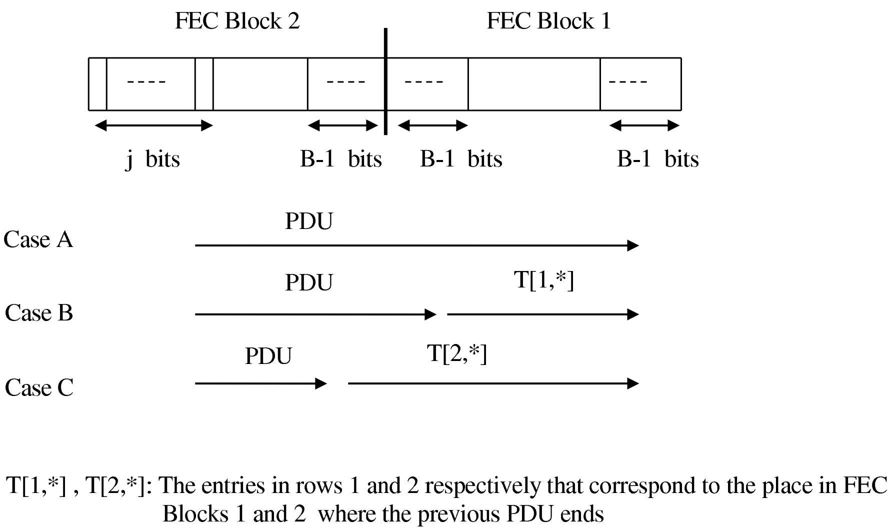

Figure 3: Compuing entry $T[2,j], 1 \leq j \leq B$ in the table of algorithm *Division-Find*.

Lemma 1. *The value of every entry in row k of T, $2 \leq k \leq L-1$, is computed in $O(k)$*

Proof. Consider an entry $T[k, j], F-(B-2) \leq j \leq F$. In order to compute this entry one needs to consider two possibilities. The first one corresponds to the case that the next PDU begins at the start of FEC Block number $k-1$. This case has the value $T[1, k-1]$. The other possibility corresponds to the case where a PDU begins at bit j of FEC Block k. This PDU can end, according to Theorem 2, at $2(k-1)$ different Starting and Ending edges. Thus, we need to choose the maximum among $2(k-1)+1 = 2k-1$ cases, where each case is computed in $O(1)$, possibly using entries from previous rows.

Considering an entry $T[k, j], 1 \leq j \leq B$, the arguments are similar to the case above. □

Theorem 3. *The time complexity of Division-Find is $O(L^2B)$.*

Proof. First consider the computation of the entries in row $k, 2 \leq k \leq L-1$. In such a row there are $2B-1$ entries and each one is computed in $O(k)$(Lemma 1). Thus, row k is computed in $O(B \cdot k)$. Summing over all the rows k we get that their entries are computed in $O(L^2B)$. In row 1 we compute only B entries, each in $O(1)$, and in row L we compute entries $T(L, 1)$ and $T[1, O+X \cdot B]$ (see above) in $O(L)$. The Theorem follows. □

2.4.1 The Case $2B-1 \geq F$

Notice that if $2B-1 \geq F$ then a PDU can end at every position within a FEC Block. Therefore, algorithm *Division-Find* is changed to contain only F entries in any row, and its time complexity is $O(L^2F)$.

Remark 1. *It is sometimes possible to receive the same optimal B-Goodput in a Burst in different divisions, such that the divisions contain different number of Data Blocks. For example, for $L = 2$ FEC Blocks, $F = 480$ bits, $B = 45$ bits, $O = 45$ bits and $p = 0.9$ there are two divisions that yield the maximum B-Goodput. In one division there is one PDU with 20 Data Blocks and in another division there are 2 PDUs, each being defined over a separate FEC Block, with 9 Data Blocks each. Our algorithm is implemented to choose the division with the largest number of Data Blocks.*

2.5 Modulation/Coding Scheme (MCS) Selection

IEEE 802.16e/WiMAX enables the use of the following Modulation/Coding schemes (MCSs) (IEEE, 2005): QPSK-1/2, QPSK-3/4, 16QAM-1/2, 16QAM-3/4, 64QAM-1/2, 64QAM-2/3, 64QAM-3/4 and 64QAM-5/6. 64QAM-1/2 is practically not used and so we will not consider this scheme any further (Alpert et al., 2010).

Recall that when a Burst is defined, actually it uses *slots* in the Physical layer. In any MCS the set of slots in a Burst is divided into groups such that any group is a FEC Block. In every MCS it is possible to define groups of slots of different sizes, resulting in FEC Blocks of different sizes. Here we only consider the largest FEC Blocks that are possible in the MCSs. We denote by j the number of slots, in every MCS, needed to define the largest FEC Block. We show the value of j for every MCS in Table 1, together with F, the number of bits that the largest FEC Block contains. We also show the success probability p of the largest FEC Block in every MCS and in several values of the SNR (Signal-to-Noise-Ratio). An entry with $*$ stands for N/A, which means that the success probability of a FEC Block in the considered MCS and SNR is 0 . These probabilities are taken from (Jum, 2010). The input from (Jum, 2010) contains graphs that address, for every MCS allowed in WiMAX, and for many realistic SNR values, the success probability for all possible length FEC Blocks in the considered MCS. We see from Table 1 that for low SNRs (bad channels) only few MCSs are applicable, while in high SNRs all the MCSs are applicable.

We also see that there is a trade-off in using the set of slots of a Burst. On one hand it is possible to decide on a reliable MCS to be used in the Burst. However, the number of FEC Blocks, and so the number of bits in the Burst, is low. On the other hand, a less reliable MCS results in more FEC Blocks and bits in the Burst, but with a smaller success probability of the FEC Blocks.

2.6 Performance Results

One criteria to decide on the best MCS is the *B-Goodput*. In Table 2 we show the *B-Goodput* for every MCS in every SNR value between 2 to 12 dB, for the case of $S = 900$ slots, $B = 128$ bits and $O = 104$ bits. $B = 128$ bits is the smallest Data Block size that is possible in IEEE 802.16e (IEEE, 2005). With $O = 104$ bits we assume that a PDU contains the GMH and the CRC fields of 6 and 4 bytes respectively as overhead, and one Fragmentation SubHeader (FSH) of 3 bytes, which is used when a PDU contains Data Blocks (IEEE, 2005). The results in Table 2 are received by using algorithm *Division-Find*. According to the *B-Goodput* criteria QPSK-1/2 can be chosen as the best MCS to use in every SNR. However,

Table 1: The number of slots j, the number of data bits F and the success probability p in various SNR values of the largest FEC Block in various MCSs.

MCS	j	F	SNR								
			2	2.5	3	3.5	4	4.5	5	5.5	6
QPSK 1/2	10	480	0.998	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999
QPSK 3/4	6	432	0.38	0.85	0.96	0.998	0.999	0.999	0.999	0.999	0.999
16QAM-1/2	5	480	*	*	0.43	0.82	0.976	0.998	0.999	0.999	0.999
16QAM-3/4	3	432	*	*	*	*	*	*	0.42	0.79	0.957
64QAM-2/3	2	384	*	*	*	*	*	*	*	*	*
64QAM-3/4	2	432	*	*	*	*	*	*	*	*	*
64QAM-5/6	2	480	*	*	*	*	*	*	*	*	*

MCS	SNR											
	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12
QPSK 1/2	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999
QPSK 3/4	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999
16QAM-1/2	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999
16QAM-3/4	0.995	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999
64QAM-2/3	*	*	*	0.56	0.79	0.941	0.991	0.999	0.999	0.999	0.999	0.999
64QAM-3/4	*	*	*	0.33	0.46	0.73	0.92	0.990	0.999	0.999	0.999	0.999
64QAM-5/6	*	*	*	*	*	0.3	0.41	0.45	0.8	0.959	0.994	0.999

Table 2: The number of slots j, the number of data bits F and the *B-Goodput* in various MCSs and SNR values, for the case $S = 900$ slots, $B = 128$ bits and $O = 104$ bits.

MCS	j	F	SNR								
			2	2.5	3	3.5	4	4.5	5	5.5	6
QPSK 1/2	10	480	0.957	0.969	0.969	0.969	0.969	0.969	0.969	0.969	0.969
QPSK 3/4	6	432	0.225	0.589	0.791	0.955	0.969	0.969	0.969	0.969	0.969
16QAM-1/2	5	480	*	*	0.254	0.548	0.847	0.957	0.970	0.970	0.970
16QAM-3/4	3	432	*	*	*	*	*	*	0.249	0.511	0.781
64QAM-2/3	2	384	*	*	*	*	*	*	*	*	*
64QAM-3/4	2	432	*	*	*	*	*	*	*	*	*
64QAM-5/6	2	480	*	*	*	*	*	*	*	*	*

MCS	SNR											
	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12
QPSK 1/2	0.969	0.969	0.969	0.969	0.969	0.969	0.969	0.969	0.969	0.969	0.969	0.969
QPSK 3/4	0.969	0.969	0.969	0.969	0.969	0.969	0.969	0.969	0.969	0.969	0.969	0.969
16QAM-1/2	0.970	0.970	0.970	0.970	0.970	0.970	0.970	0.970	0.970	0.970	0.970	0.970
16QAM-3/4	0.969	0.969	0.969	0.969	0.969	0.969	0.969	0.969	0.969	0.969	0.969	0.969
64QAM-2/3	*	*	*	0.373	0.527	0.741	0.897	0.967	0.967	0.967	0.967	0.967
64QAM-3/4	*	*	*	0.196	0.273	0.453	0.911	0.920	0.969	0.969	0.969	0.969
64QAM-5/6	*	*	*	*	*	0.172	0.241	0.267	0.519	0.800	0.925	0.970

Table 3: The number of slots j, the number of data bits F and the average integral number of successfully transmitted Data Blocks in various MCSs and SNR values, for the case $S = 900$ slots, $B = 128$ bits and $O = 104$ bits.

MCS	j	F	SNR								
			2	2.5	3	3.5	4	4.5	5	5.5	6
QPSK 1/2	10	480	323	327	327	327	327	327	327	327	327
QPSK 3/4	6	432	114	298	400	483	490	490	490	490	490
16QAM-1/2	5	480	*	*	172	370	572	646	655	655	655
16QAM-3/4	3	432	*	*	*	*	*	*	252	517	790
64QAM-2/3	2	384	*	*	*	*	*	*	*	*	*
64QAM-3/4	2	432	*	*	*	*	*	*	*	*	*
64QAM-5/6	2	480	*	*	*	*	*	*	*	*	*

MCS	SNR											
	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12
QPSK 1/2	327	327	327	327	327	327	327	327	327	327	327	327
QPSK 3/4	490	490	490	490	490	490	490	490	490	490	490	490
16QAM-1/2	655	655	655	655	655	655	655	655	655	655	655	655
16QAM-3/4	981	981	981	981	981	981	981	981	981	981	981	981
64QAM-2/3	*	*	*	503	711	1000	1210	1305	1305	1305	1305	1305
64QAM-3/4	*	*	*	297	414	687	1383	1410	1471	1471	1471	1471
64QAM-5/6	*	*	*	*	*	290	406	451	875	1350	1560	1636

in QPSK-1/2 the Burst contains only 90 FEC Blocks of 480 bits each. On the other hand, 64QAM-5/6 contains 450 FEC Blocks of 480 bits each. This enables the transmission of more bits in the Burst, although with a reduced success probability.

Therefore, in Table 3 we show the average number of Data Blocks that are transmitted successfully in the Burst, again for every MCS in every SNR. The results in Table 3 are received again by algorithm *Division-Find*. This time we divide the number of successfully transmitted Data bits by a Data Block size. According to this criteria, the best MCS can change from one SNR to another. As the channel becomes better, i.e., higher SNR values, the MCS that enables to transmit a larger number of bits in a Burst is becoming the best MCS to use. For example, in SNR=12 dB the best MCS is 64QAM-5/6 because the *B-Goodput* of all the MCSs are about the same, but 64QAM-5/6 enables the largest number of bits in the Burst. For SNR= 9 dB , 64QAM-2/3 enables to transmit successfully the largest number of Data Blocks, although its *B-Goodput* is only the 5^{th} in size. The larger number of bits in a Burst with 64QAM-2/3 enables to compensate for the lower *B-Goodput*.

3 CONCLUSIONS

We suggest two performance criteria for the division of a given Burst into PDUs that contain Data Blocks. The first criteria measures the *relation* between the number of successfully transmitted Data bits to the Burst size. The second criteria measures the *absolute* number of successfully transmitted Data bits in the Burst. The two criteria lead to different choices of the optimal MACS to use in the Burst, given an SNR. From the user perspective it seams that the second criteria is more important. In this case, as a rule of thumb, the best MCS in a given SNR is one of the two MCSs that enable to transmit the largest number of Data Blocks in the Burst.

REFERENCES

Alpert, Y., Segev, J., and Sharon, O. (2010). Advanced coupled phy and mac scheduling in ieee 802.16 wimax systems. *Physical Communication*, 3:287–298.

Alpert, Y., Segev, J., and Sharon, O. (2013). Towards an optimal transmission of sdus by msc in ieee 802.16 wimax systems.

Huang, F. H. (1997). Evaluation of soft output decoding for turbo codes. Master's thesis, EE Faculty, Virginia Polytechnic Institute. http://scholar.lib.vt.edu/theses/available/edit-71897-15815/unrestricted.

IEEE (2005). *IEEE 802.16e, Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems*. IEEE Standards for Local and Metroplitan Area Networks.

Jum, X. (2010). ZTE Corporation, China, Personal Communication.

WiMAX (2008). Wimax forumtm mobile radio conformance tests (mrct), release 1.0. Approved Specification (Revision 2.2.0).