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Abstract	The contribution compares different FEC schemes in terms of data throughput under different ARQ scenarios. System is assumed to implement adaptive modulation and coding, i.e. adaptive burst profile selection. Among several interesting conclusions, it is shown that the coding scheme specified in the current working document provides good support for systems without ARQ but is disadvantageous for systems that employ ARQ to obtain higher throughput.
Purpose	Assist 802.16 in finalizing 802.16ab working document.
Notice	
Release	
Patent Policy and Procedures	

FEC Performance with ARQ and Adaptive Burst Profile Selection

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Introduction

This might look like "just another contribution on FEC performance". The novelty of the present contribution is that, instead of analyzing FEC performance as a separate unit, FEC, modulation and ARQ are jointly analyzed as a system. The benchmark used in this analysis is the data throughput since maximizing the throughput is the final target of 802.16 FWA systems.

The relationship between throughput and signal to noise ratio (SNR) is analyzed under three ARQ scenarios:

- No ARQ, i.e. no retransmission.
- Each data packet/fragment is allowed one retransmission (for minimal delay)
- There is no limit on the number of retransmissions allowed for each data packet/fragment

For all scenarios, we assume the system employs adaptive modulation and coding, i.e. it selects the burst profile (modulation and coding) such that it maximizes the throughput while maintaining the packet error rate (PER) under a preset threshold PER_0.

Simulations

We considered the 6 burst profiles currently specified by 802.16ab working document for the 256-FFT OFDM mode, using concatenated RS/CC FEC scheme. For consistency, the parameters of the 6 burst profiles are shown in Table 1.

Burst profile	Modulation	Uncoded Bytes per Symbol N_{UBPS}	Coded Bytes per Symbol N_{CBPS}	Overall Rate	RS Code	CC Rate
1	QPSK	24	48	1/2	(32,24,4)	2/3
2	QPSK	36	48	3/4	(40,36,2)	5/6
3	16QAM	48	96	1/2	(64,48,8)	2/3
4	16QAM	72	96	3/4	(80,72,4)	5/6
5	64QAM	96	144	2/3	(108,96,6)	3/4
6	64QAM	108	144	3/4	(120,108,6)	5/6

Table 1: Burst profiles using concatenated RS/CC scheme

We considered also 6 additional burst profiles that use the same combinations of modulation and coding rate but with convolutional coding (CC) instead of concatenated coding. The parameters of these 6 burst profiles are shown in Table 2.

Burst profile	Modulation	Uncoded Bytes per Symbol N_{UBPS}	Coded Bytes per Symbol N_{CBPS}	CC Rate
1	QPSK	24	48	1/2
2	QPSK	36	48	3/4
3	16QAM	48	96	1/2

4	16QAM	72	96	3/4
5	64QAM	96	144	2/3
6	64QAM	108	144	3/4

Table 2: Burst profiles using CC-only

PER simulations

All 12 burst profiles have been first simulated to obtain the PER(SNR) curves for a super-packet of 864 bytes (smallest common multiple of all block sizes). Then the PER was scaled to a packet size of 128 bytes, which is the size of the ARQ block according to the current 802.16ab working document. The results for all 12 burst profiles are shown in Figure 1.

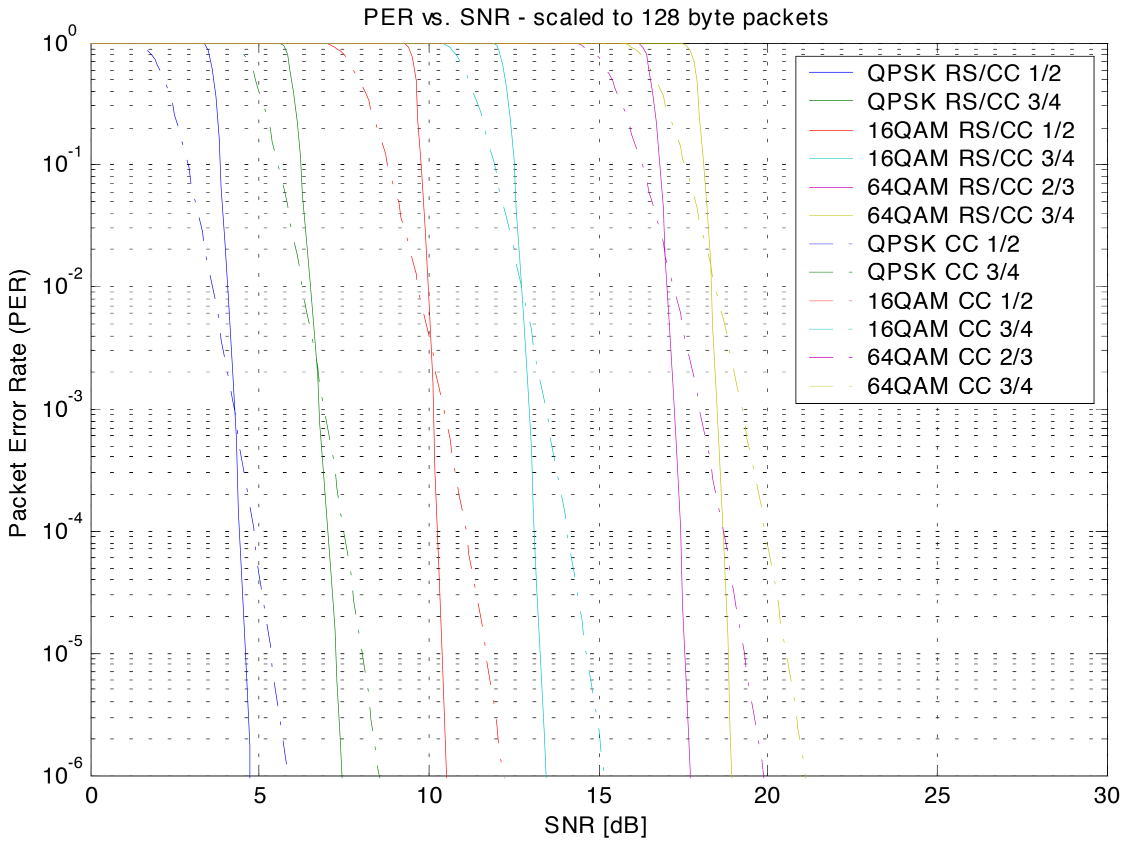

Figure 1: PER vs. SNR for 128-byte packets

We used several ideal parameters to obtain the maximum achievable performance for both coding schemes and to facilitate better statistical estimation. Here are the parameters used for this simulations:

- More than 10^{12} data bits used to estimate PER=10^{-6} for each burst profile
- AWGN channel
- SNR does not include losses due to guard interval and pilots
- Ideal channel equalization
- Perfect bit interleaving
- Soft-decision Viterbi decoding for both coding schemes with floating-point precision
- Tail-biting block equal to the size of an OFDM symbol
- Length of the trace-back memory larger that the symbol size

- RS decoder with perfect erasures
- Perfect erasures generated by comparing the Viterbi output with the transmitted bit stream (very ideal setup).

Throughput without ARQ

A system without ARQ has no chance to improve the PER provided by the physical layer. Such a system will maximize the throughput by choosing the highest burst profile that meets PER < PER_0 for the given SNR. For each burst profile, the throughput for a given SNR can be computed from PER(SNR) as:

$$N_{BPS}(SNR) = N_{UBPS}\,(1\text{-}PER(SNR)) \quad \text{if } PER(SNR) < PER_0$$
$$= 0 \quad \text{otherwise}$$

where N_{BPS} is the average number of bytes transmitted successfully in one OFDM symbol after ARQ and N_{UBPS} is the number of uncoded bytes per symbol provided by the corresponding burst profile. The overall system throughput for a given SNR is the maximum across throughputs for all burst profiles.

Throughput with one retransmission

A system with ARQ that allows only one retransmission can improve significantly the PER provided by the physical layer. We assume that retransmissions are not constrained to use the same burst profile as the first transmission. Let $PER_1(SNR)$ and N_{UBPS1} be the PER and number of uncoded bytes per symbol for the burst profile used for the first transmission and let $PER_2(SNR)$ and N_{UBPS2} be the same for the retransmission. Then, the overall packet error rate is $PER_1(SNR)\cdot PER_2(SNR)$ and the overall throughput is given by:

$$N_{BPS}(SNR) = (1 - PER_1(SNR)\cdot PER_2(SNR))\cdot N_{UBPS1}/(1+PER_1(SNR)\cdot N_{UBPS1}/N_{UBPS2})\ldots$$
$$\text{if } PER_1(SNR)\cdot PER_2(SNR) < PER_0$$
$$= 0 \quad \text{otherwise}$$

where N_{BPS} is again the average number of bytes transmitted successfully in one OFDM symbol. The overall system throughput for a given SNR is the maximum across throughputs for all possible pairs of burst profiles.

Throughput with arbitrary number of retransmissions

A system with ARQ that allows an unlimited number of retransmissions can theoretically improve the PER provided by the physical layer to the point that the overall PER = 0. We let again retransmissions use a different burst profile than the first transmission but, for simplicity, we assume that all retransmissions use the same burst profile. Let $PER_1(SNR)$ and N_{UBPS1} be the PER and number of uncoded bytes per symbol for the burst profile used for the first transmission and let $PER_2(SNR)$ and N_{UBPS2} be the same for the retransmissions. Then, if k retransmissions are allowed, the overall packet error rate is $PER_1(SNR)\cdot PER_2^k(SNR)$ and the overall throughput is given by:

$$N_{BPS}(SNR) = (1 - PER_1(SNR)\cdot PER_2^k(SNR))\cdot N_{UBPS1}/(1+PER_1(SNR)\cdot(1- PER_2^k(SNR))/(1-\ldots$$
$$\ldots PER_2(SNR))\cdot N_{UBPS1}/N_{UBPS2}) \quad \text{if } PER_1(SNR)\cdot PER_2^k(SNR) < PER_0$$
$$= 0 \quad \text{otherwise}$$

where N_{BPS} is again the average number of bytes transmitted successfully in one OFDM symbol. If unlimited number of retransmissions are allowed (i.e. $k \rightarrow \infty$), the overall packet error rate can be made arbitrarily small and the overall throughput is given by:

$$N_{BPS}(SNR) = N_{UBPS1}/(1+PER_1(SNR)/(1-PER_2(SNR))\cdot N_{UBPS1}/N_{UBPS2})$$

In both cases (k is finite and k is infinite), the overall system throughput for a given SNR is the maximum across throughputs for all possible pairs of burst profiles.

Results

For both ARQ scenarios, we have simulated the following four combinations:

- First transmission and retransmission(s) use RS/CC
- First transmission uses RS/CC and retransmission(s) use CC-only
- First transmissions and retransmission(s) use CC-only
- First transmission uses CC-only and retransmission(s) use RS/CC

The target PER for all simulations was $PER_0 = 10^{-6}$.

Figure 2 shows the computed throughput for all four combinations with the ARQ limited to a single retransmission. We note that, when CC-only is used for the first transmission, the system provides a higher throughput, regardless of the coding used for retransmissions. The advantage provided by the CC-only scheme can be as high as 1.2dB (SNR=8-10dB). We also note that there is some advantage (less than 0.3dB around SNR=5dB and less than 0.1dB around SNR=17dB) in using RS/CC scheme for retransmissions.

Figure 3 shows the computed throughput for all four combinations without any limit on the number of retransmissions. We note again that that, when CC-only is used for the first transmission, the system provides a higher throughput, regardless of the coding used for retransmissions. The advantage provided by the CC-only scheme can be as high as 1.2dB (SNR=8-10dB). We also note that for SNR>4dB there is little difference between using CC or RS/CC as the coding for retransmissions. There is just a little advantage (less than 0.1dB) towards using CC-only in several places. However, for SNR<4dB, the CC-only scheme offers tremendous advantages (up to 3dB) when used for retransmissions.

Another interesting analysis is to see how much throughput improvement the ARQ can bring to the system. Figure 4 and Figure 5 compare the throughput with and without ARQ for both coding schemes RS/CC and CC-only (same scheme used for first transmission and for retransmissions). Figure 4 shows the results for a single retransmission and Figure 5 shows the results for multiple retransmissions. We note that ARQ improves the SNR with up to 1.5dB for the RS/CC scheme and up to 4dB for the CC-only scheme. Overall the best system without ARQ is up to 2dB worse than the best system using ARQ.

Looking closely at Figure 2 and Figure 3 we see little difference between using one retransmission and multiple retransmissions. This is because we allow the retransmission use a lower burst profile than the one used for the first transmission. Regardless of how high is the PER on the first transmission, the system can choose the profile for the retransmission enough low such that the overall PER is smaller than PER_0. This is true as long there is a lower burst profile to choose from, and thus we see a significant difference only for SNR < 4.2dB. More details about this subject can be found in the next section.

Another interesting remark is that systems without ARQ suffer a stair-like degradation of the throughput with the SNR. Therefore, in order to accommodate channel variations, a larger link margin must be used. Systems using ARQ with concatenated RS/CC scheme have a similar stair-like degradation and thus they require also a large link margin. However, systems with ARQ and CC-only scheme have a very smooth throughput degradation with the SNR. Such systems may operate properly with a much smaller link margin.

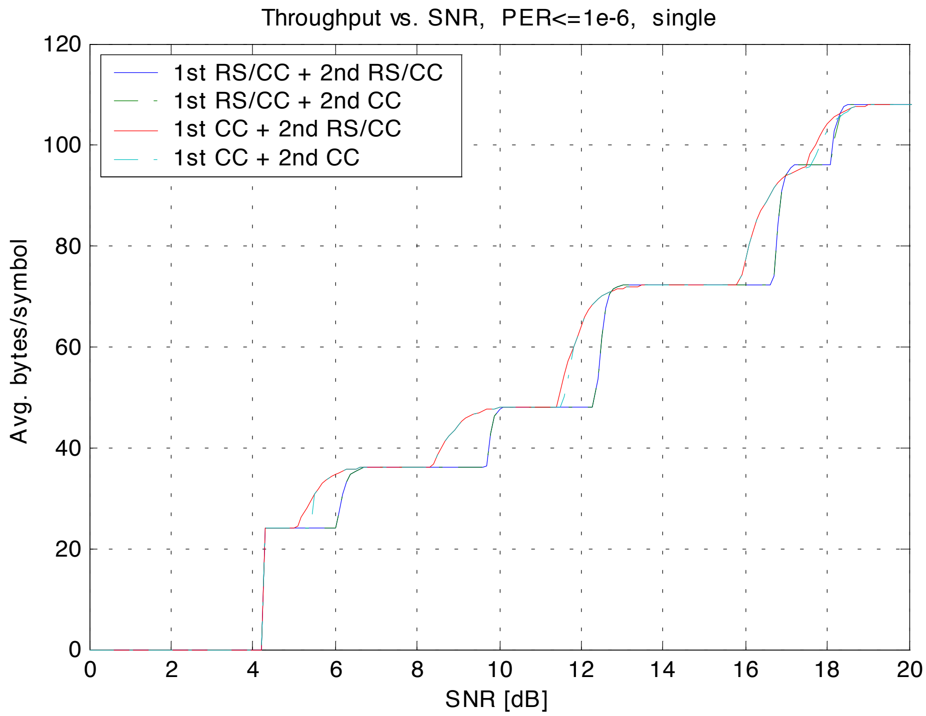

Figure 2: Throughput with RS/CC and CC for single retransmission

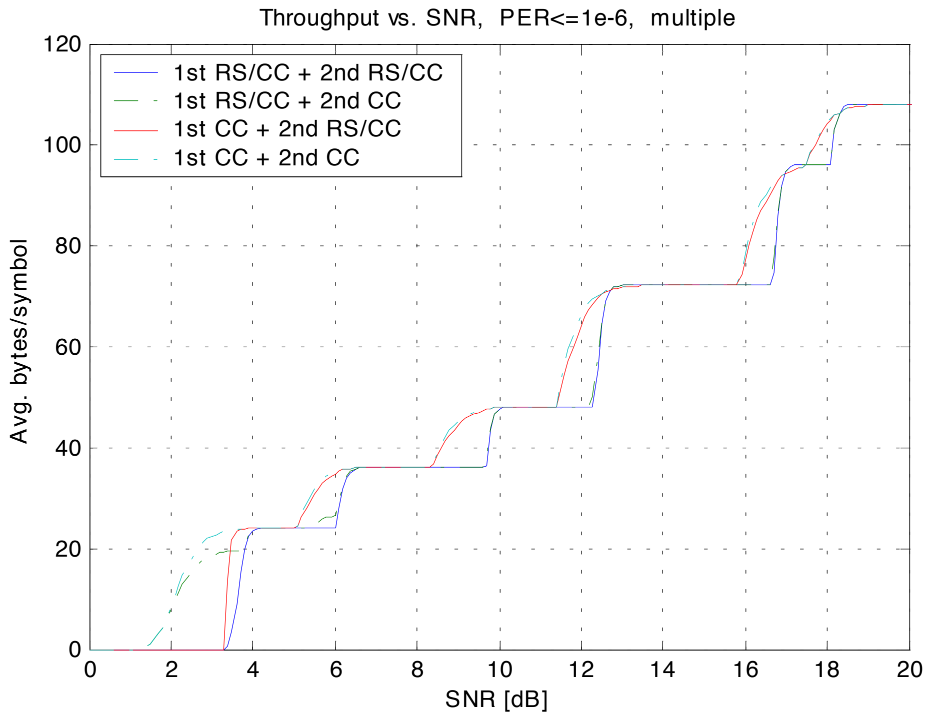

Figure 3: Throughput with RS/CC and CC for multiple retransmissions

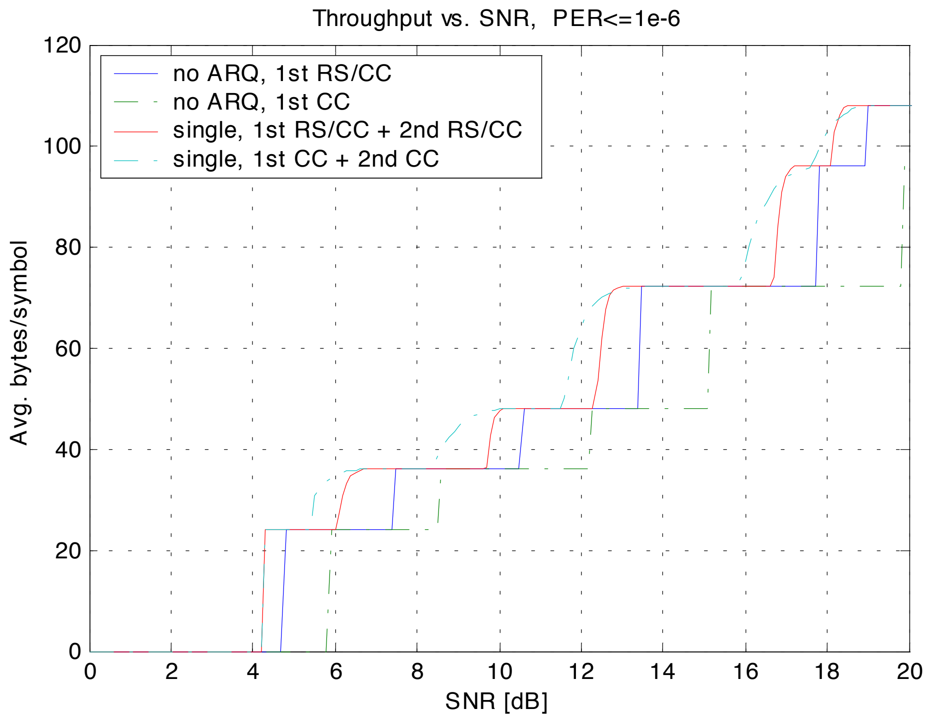

Figure 4: Throughput with and without ARQ for single retransmission

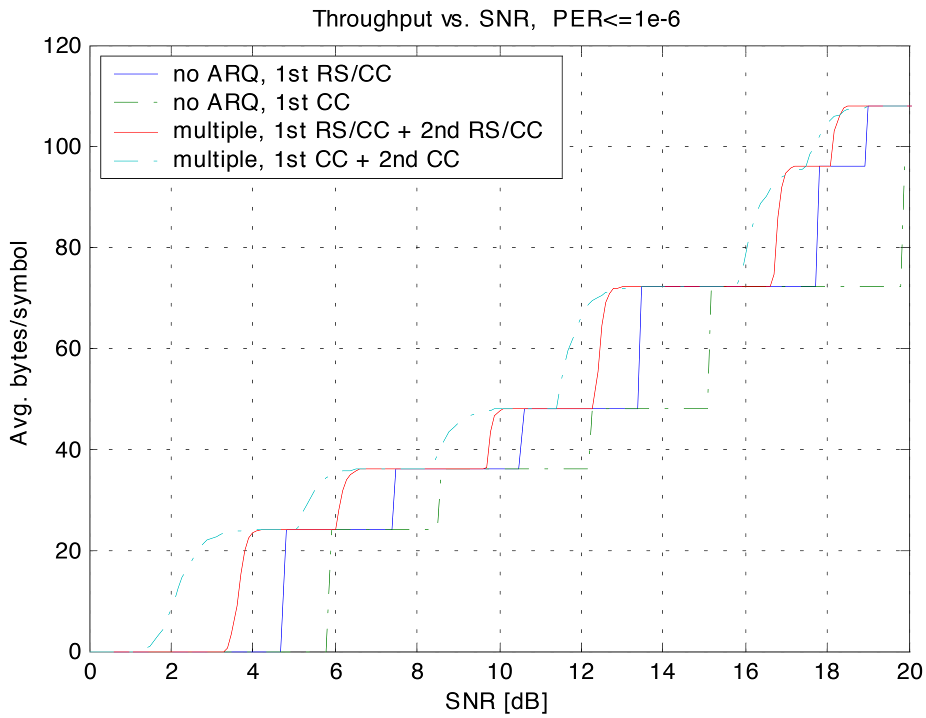

Figure 5: Throughput with and without ARQ for multiple retransmissions

Comments and explanations

In order to understand why the CC-only performs better than RS/CC with ARQ and reversely without ARQ, let us imagine that the system starts operating with an excellent (very high) SNR and that the SNR slowly degrades.

Systems without ARQ

Having an excellent SNR, the adaptive modulation and coding will initially select the highest burst profile, in our case 6, to maximize the system throughput. If the SNR degrades to the point that the burst profile 6 does not meet anymore the $PER(6,SNR)<PER_0$ requirement, the adaptive modulation and coding will change the burst profile from 6 to 5. Further degradation will cause switching to profile 4, and so on. The throughput is maximized by changing the burst profile at the lowest SNR possible. We note that the decision to change to a lower burst profile is caused by the comparison between PER(SNR) and PER_0. Figure 1 shows that the concatenated RS/CC scheme clearly outperforms the CC-only scheme for $PER=10^{-6}$.

Systems with a single retransmission

Having an excellent initial SNR, the adaptive modulation and coding will select the highest burst profile for both the first transmission and the retransmission. If the SNR degrades to the point that $PER^2(6,SNR)$ equals PER_0, the adaptation algorithm can either lower both burst profiles or change only the burst profile for the retransmission. The new overall PER will be $PER^2(5,SNR)$ in the first case and $PER(6,SNR)\cdot PER(5,SNR)$ in the second. It is very likely that the second option will be used because it preserves the highest throughput for the first rate. Upon further SNR degradation, the burst profile may be further stepped down and the process continues until the packet error rate for the first transmission will become so high that better throughput can be obtained by stepping down the burst profile for the first transmission. Thus it is possible to step down several burst profiles for the retransmission before stepping down the burst profile for the first transmission. Figure 6 shows the burst profile changes obtained with ARQ when single retransmission is used. We note that with CC-only scheme, the difference between burst profiles used for the first transmission and for retransmission can be as high as two. With RS/CC the difference is maximum one.

Note that the data rate provided by the retransmission has little contribution to the overall throughput because it applies only to a fraction of the packets. Therefore, changing the burst profile for the first transmission at the lowest SNR possible maximizes the overall throughput. This change occurs when the loss in throughput caused by retransmissions (which is equal to a small factor times the PER on the first transmission) is higher than the throughput difference between current profile and the next lower profile. Figure 7 shows the PER for the first transmission for a system with a single retransmission. The five peeks correspond the PER/SNR levels at which the adaptive modulation and coding switches to a lower burst profile for the first transmission. We note that these levels are up to 1.2dB higher for RS/CC scheme. We also note the PER levels are in the range of 7% to 23% for the CC-only scheme and 5% to 24% for the RS/CC scheme. The SNR and PER levels at which burst profiles are changed are shown in Table 3 for CC-only and in Table 4 for RS/CC. The highlighted rows in these tables correspond to changes in the burst profile for the first transmission. Figure 1 shows that the CC-only scheme clearly outperforms the RS/CC scheme, for PER>5%.

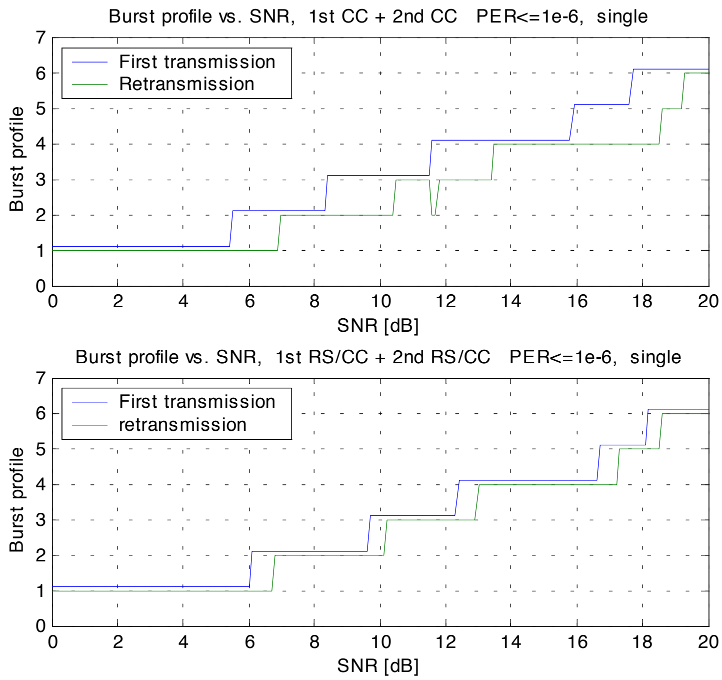

Figure 6: Burst profiles vs. SNR for $PER_0 = 10^{-6}$, single retransmission

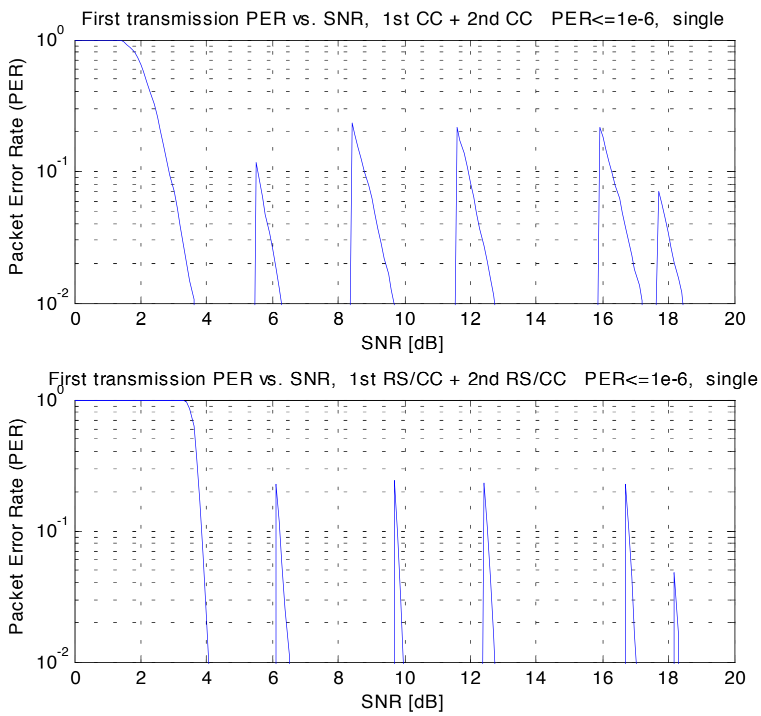

Figure 7: First transmission PER vs. SNR for $PER_0 = 10^{-6}$, single retransmission

SNR [dB]	Burst profile 1st transmission	Burst profile retransmission	PER [%]
19.9	6	6	0.01
19.2	6	5	0.08
18.5	6	4	0.68
17.6	**5**	**4**	**7.12**
15.8	**4**	**4**	**21.90**
13.4	4	3	0.08
11.7	4	2	13.70
11.5	**3**	**3**	**21.87**
10.4	3	2	0.08
8.3	**2**	**2**	**23.15**
6.9	2	1	0.07
5.4	**1**	**1**	**11.56**

Table 3: Burst profile changes with CC for $PER_0 = 10^{-6}$, single retransmission

SNR [dB]	Burst profile 1st transmission	Burst profile retransmission	PER [%]
19.9	6	6	0.00
18.5	6	5	0.03
18.1	**5**	**5**	**4.72**
17.2	5	4	0.04
16.6	**4**	**4**	**22.42**
12.9	4	3	0.05
12.3	**3**	**3**	**23.29**
10.1	3	2	0.03

9.6	**2**	**2**	**24.43**
6.7	2	1	0.08
6.0	**1**	**1**	**22.73**

Table 4: Burst profile changes with RS/CC for $PER_0 = 10^{-6}$, single retransmission

Systems with multiple retransmissions

With an arbitrary number of retransmissions, the system can meet the required PER_0 without the need to lower the burst profile for retransmissions. However, it needs to lower both burst profiles when the loss in throughput caused by retransmissions is higher than the throughput difference between current profile and the next lower profile. Figure 8 shows the burst profile changes obtained with multiple retransmissions and Figure 9 shows the PER for the first transmission. We note that for both coding schemes the burst profiles used for the first transmission and for retransmissions are changed simultaneously. We also note that the burst profile changes occur at higher SNR for the RS/CC scheme than for the CC-only scheme, with a difference of up to 1.2dB. The PER levels at which burst profiles change are in the range of 11% to 32% for CC-only and 4% to 22% for RS/CC. The PER and SNR levels at which burst profiles are changed are summarized in Table 5 for CC-only scheme and Table 6 for RS/CC scheme. Again, Figure 1 shows that the CC-only scheme clearly outperforms the RS/CC scheme, for PER>4%.

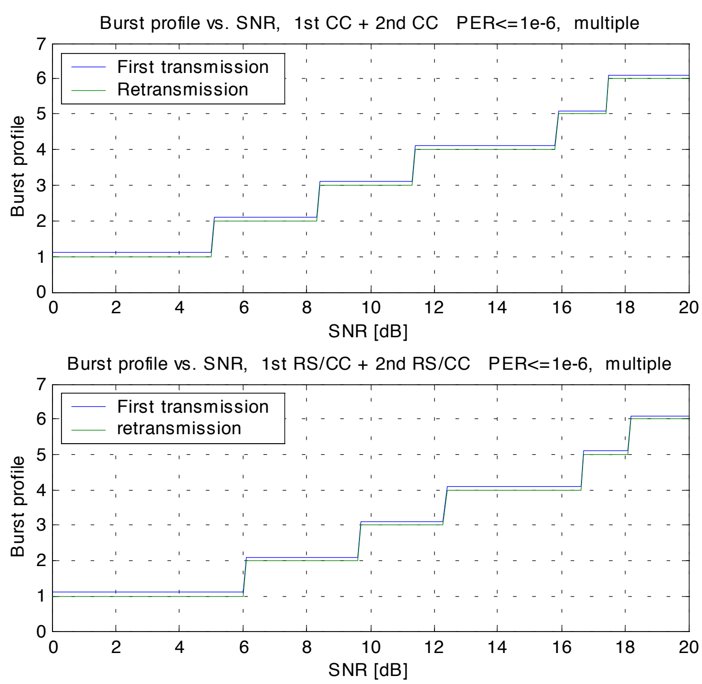

Figure 8: Burst profiles vs. SNR for $PER_0 = 10^{-6}$, multiple retransmissions

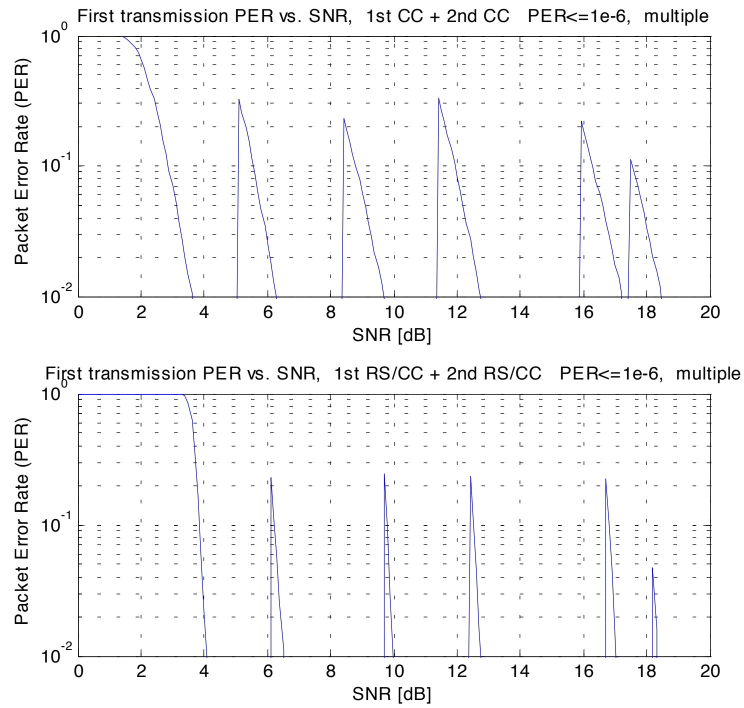

Figure 9: First transmission PER vs. SNR for $PER_0 = 10^{-6}$, multiple retransmissions

SNR [dB]	Burst profile 1st transmission	Burst profile retransmission	PER [%]
19.9	6	6	0.01
17.4	**5**	**5**	**11.28**
15.8	**4**	**4**	**21.90**
11.3	**3**	**3**	**33.31**
8.3	**2**	**2**	**23.15**
5.0	**1**	**1**	**32.38**

Table 5: Burst profile changes with CC for $PER_0 = 10^{-6}$, multiple retransmissions

SNR [dB]	Burst profile 1st transmission	Burst profile retransmission	PER [%]

19.9	6	6	0.00
18.1	**5**	**5**	**4.72**
16.6	**4**	**4**	**22.42**
12.3	**3**	**3**	**23.29**
9.6	**2**	**2**	**24.43**
6.0	**1**	**1**	**22.73**

Table 6: Burst profile changes with RS/CC for $PER_0 = 10^{-6}$, multiple retransmissions

Conclusion

This is the first contribution to analyze the combined performance of adaptive modulation, coding and ARQ. We developed a simple framework that permits throughput vs. SNR comparisons between different ARQ models. The contribution introduces an efficient ARQ method that confines the ARQ delay to a single retransmission but obtains almost the same performance as with multiple retransmissions. The contribution compares in terms of throughput the systems without ARQ with systems using single and multiple retransmissions. It also compares concatenated RS/CC and CC-only FEC schemes under all ARQ scenarios. The main conclusions are shown below:

Throughput without ARQ

For systems without ARQ, the concatenated RS/CC scheme is superior to the CC-only scheme. Depending on PER_0, concatenated codes may have up to a 2.2dB advantage over CC. This result is explained by Figure 1 where we can see that at $PER_0 = 10^{-6}$, the RS/CC scheme outperforms CC-only scheme for all combinations of modulation and coding rate. This explains why systems that do not have a mandatory return channel and hence no ARQ, use concatenated codes. A typical example here is the digital broadcasting standards DVB and HDTV.

Throughput with ARQ

For systems with ARQ, the CC-only scheme is superior to the concatenated RS/CC scheme under both ARQ scenarios. Depending on the target PER_0 and the number of retransmissions allowed, the CC-only scheme may provide up to 1.5dB advantage over concatenated codes. This result is explained by the fact that for such systems the most important factor in optimizing the throughput is the coding performance for high PER (4% to 32%). In Figure 1 we can see that CC-only scheme outperforms the RS/CC scheme for PER > 1%.

ARQ vs. no ARQ

Systems with ARQ offer superior throughput than systems without ARQ. Depending on the number of retransmissions allowed, systems with ARQ may have up to 2-4dB advantage. However, the coding scheme specified in the current 802.16ab working document is optimized for systems without ARQ. The chosen coding scheme clearly disadvantage the systems with ARQ that can offer the best overall performance.

What PER level shall be used to compare different coding options?

For systems without ARQ the PER level should be the desired PER_0. For systems with ARQ the PER level is in the range 4% to 32% depending on the burst profiles used.

Link margin with and without ARQ

The link margin needed to accommodate channel variations is shown to be larger for systems that suffer stair-like degradation of the throughput with the SNR. It is shown that systems using ARQ and CC-only scheme have a very smooth throughput degradation with SNR and thus they require much smaller link margin.

Do we need BPSK?

We noticed that the efficiency of ARQ with a single retransmission is very much dependent on the existence of burst profiles with a lower data rate than the rate used for the first transmission. Thus, it may be important to add the two BPSK burst profiles - currently defined only for the unlicensed bands – to the licensed bands too. These can improve the SNR range with 3dB. It may be important to specify that these two modes shall be used only for management messages (e.g. BW request) and for retransmissions.

Other implications

The approach described in this contribution can be used to make knowledgeable decisions on the optimum choice of other parameters like preamble and GI. The choice of these parameters is based on tradeoffs between the performance (e.g. SNR degradation introduced by the channel estimation) and the overhead (e.g. caused by the length of the preamble). Therefore these parameters should be also analyzed in terms of the overall system throughput.

Proposals

If the 802.16 group considers ARQ as mandatory, then CC-only scheme shall be the only mandatory coding scheme since it provides significant better performance under ARQ than concatenated RS/CC-scheme.

If the 802.16 group considers ARQ optional, then it is important to have concatenated coding scheme as at least an option. Here there are several distinct options that may be considered:

1. Define 6 (or 8) mandatory burst profiles using CC and 6 (or 8) optional burst profiles using RS/CC
2. Define 12 (or 16) mandatory burst profiles half using CC and half using RS/CC
3. Define 6 (or 8) mandatory burst profiles using CC. Define an optional ARQ block that replaces the mandatory CRC with optional RS parity bytes.
4. Define 6 (or 8) mandatory burst profiles using CC. Define two mandatory ARQ blocks one with CRC and one with RS.

The authors of this contribution favor the last two options because:

- They simplify the RS decoder design (one fixed block size instead of 6 or 8 sizes)
- CRC is used with ARQ and becomes useless without it. Therefore it is an undesired overhead when operating with concatenated RS/CC and no ARQ.
- Limits the number of burst profiles.
- Leaves to the MAC implementation to decide how much error correction and how much error detection RS decoder will provide.

Appendix – This contribution vs. decision of the FEC Ad-Hoc group

The decision of the FEC Ad-Hoc group taken on Aug 13, 2001 was sustained by two major factors: PER threshold and performance of RS/CC with erasures. In the following we analyze these factors and we show that:

- FEC and ARQ simulations in this contribution are consistent with those shown in the Ad-Hoc group
- The results were misinterpreted in the Ad-Hoc group and this lead to a wrong decision

PER threshold

One of the factors that need to be considered when selecting the coding scheme is the PER at which coding schemes must be compared. Though the Ad-Hoc group agreed earlier to compare the coding schemes for PER=10^{-2}, the final decision was based on PER=10^{-4}. Just before the final vote was taken, Wendy Wong stated that "**our field trials show that PER=10^{-4} must be used for comparison, PER=10^{-2} add huge traffic due to ARQ**" (see minutes from 3rd FEC conference call provided by Garik Markarian). The assertion was not proven immediately but the vote was based on it. Two weeks later, on Aug 27, 2001 Wendy Wong submits the results that were supposed to back his assertion that ARQ significantly reduces the traffic when PER=10^{-2}. Figure 10 shows Wendy's results, where we can see that for PER=10^{-2} the throughput is reduced only by 7% which is much less than the cost of switching to a lower burst profile that is: 11% for switching from profile 6 to 5, 25% for switching from profile 5 to 4 and 3 to 2, or 33% for switching from profile 4 to 3 and 2 to 1.

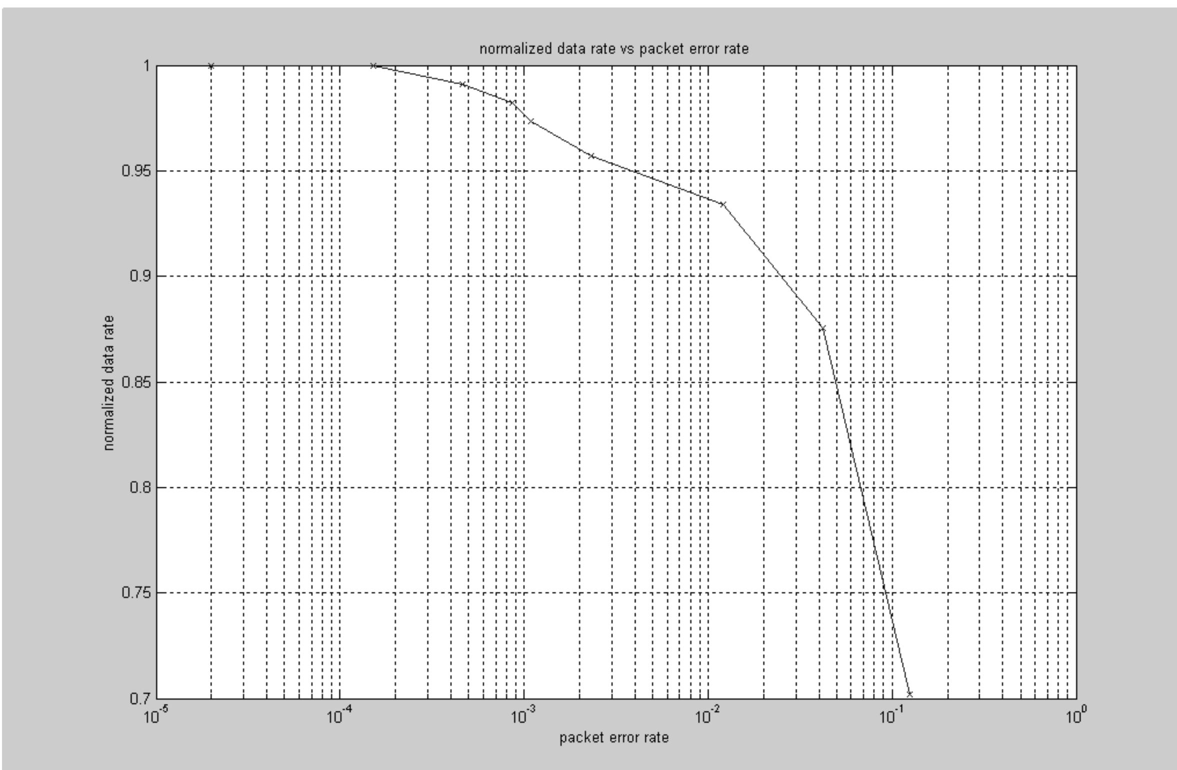

Figure 10: Throughput vs. PER according to Wendy Wong

A properly designed system will never switch from a higher burst profile to a lower one unless this helps the system throughput. Thus, the system will actually switch to a lower burst profile only when the "normalized data rate" becomes lower than 0.89, 0.75 or 0.66 depending on the current burst profile. According to Figure 10 this corresponds PER=$3 \cdot 10^{-2}$ (0.89), PER=$9 \cdot 10^{-2}$ (0.75) and PER=$20 \cdot 10^{-2}$ (0.66). Therefore, when correctly analyzed, Wendy's results show that FEC performance must be compared at PER=3%…20%. Consequently, the results shown in the present contribution are consistent with those in Wendy's paper except that those were misinterpreted when voting took place in the Ad-Hoc group.

Performance of RS/CC with erasures

A second important factor in the decision of the Ad-Hoc group was the assertion made by Yossi Segal that RS/CC decoded with erasures outperforms CC for all PER levels. Yossi Segal backed his claim with a contribution that provided two sets of results. The first set compared the two coding schemes in an AWGN channel:

- With packets of 144 bytes, the RS(64,48,8)+CC(2/3) decoded with erasures outperforms CC(1/2) for PER<$2\cdot10^{-2}$. RS/CC without erasures outperforms CC only for PER<$1\cdot10^{-3}$.
- With packets of 216 bytes, the RS(80,72,4)+CC(5/6) decoded with erasures outperforms CC(3/4) for PER<$6\cdot10^{-3}$. RS/CC without erasures may outperform CC only when PER is way below $1\cdot10^{-3}$.

These two results are consistent with ours. The small differences can be easily explained by the poor statistical accuracy used by Yossi.

The second set of results provided by Yossi compared the two coding schemes in SUI1 channel model:

- For 64QAM and rate 2/3, RS/CC with and without erasures outperforms CC-only at all PER levels with packets of 96 and 288 bytes.
- For 64QAM and rate 3/4, RS/CC with erasures outperforms CC-only at all PER levels with packets of 108 and 324 bytes. RS/CC without erasures outperforms CC-only at PER<$1\cdot10^{-1}$ under sane conditions.

However these results raise significant doubts. First, the BER and PER results are completely inconsistent. A careful look at Yossi's results shows that:

- for the same modulation, coding rate and SNR, the CC provides better BER while RS/CC provides way better PER (e.g. 96-byte packets, 15dB, rate 2/3)
- BER and PER performance for RS/CC with erasures at same SNR are suspiciously close (e.g. BER = $1\cdot10^{-3}$ and PER = $8\cdot10^{-3}$ for 96-byte packets, rate = 2/3 and SNR = 16dB).
- the relationship between PER and BER is inconsistent even with CC-only scheme

This suggests that the presented data is not statistically accurate, i.e. one or more of the following may have happened:

- different channel realizations may have been used to obtain BER and PER results
- packets and symbols may have been differently aligned for CC and concatenated schemes
- different bit interleaving schemes may have been used
- simulations may have used insufficient data

Second, according Yossi's contribution "The simulations were performed by accumulating at least 100-10000 bit errors for all schemes (1e6-20e6 bits sent)." It looks like the amount of data is far from being sufficient to acquire good statistical estimation for different channel realizations. It is also possible that different channel realizations were used to simulate the three coding schemes, which combined with the use of insufficient data may explain the inconsistencies.

Finally, there is no theoretical reasoning to assume significant differences between SUI channel models and AWGN channels in terms of coding. We recall that, according to the current 802.16ab working document, the concatenated codes do not use byte interleaving and the RS block equals exactly one OFDM symbol. If byte interleaving and/or RS block sizes larger than one OFDM-symbol were used, the difference between the concatenated RS/CC scheme and the CC-only scheme might change under burst noise and variable channels. However, according to the current working document, these features are not employed. Therefore, the channel characteristics translate after FFT into inter-symbol interference (ISI), frequency response, noise (a short impulse is spread across all carriers). We recall that bit interleaving is used to whiten the errors after slicer. Therefore the channel characteristics translate into SNR degradation after the bit de-interleaver and we should see, aside from a shift in the SNR levels, only small (if any) differences between SUI channel models and AWGN channels in terms of coding.