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Re:	IEEE 802.16m-08/024: Call for Contributions on Project 802.16m System Description Document (SDD). Target topic: ”Link Adaptation Schemes’.	
Abstract	This contribution proposes for AMC Design with Truncated HARQ	
Purpose	To be discussed and adopted by TGm for the 802.16m SDD.	
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AMC Design with Truncated HARQ

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1. Introduction

A link adaptation technique, such as the Adaptive Modulation and Coding (AMC), is usually adopted in wireless transmission to adaptively change the transmission parameters to reflect the channel quality. The change of transmission parameters may be the modulation method such as the selection of the modulation mode of QPSK, 16 QAM or 64 QAM etc. and the coding set and its coding rate such as the convolution code with rate 1/2, 2/3 or 3/4 etc. Also in the network for error control it has two basic implementation schemes such as the Forward Error Control (FEC) and Automatic Repeat Request (ARQ) and basically when the retransmission sequence is not successfully decoded at the receiver it has been discarded and the FEC encoding/decoding is independent on the successive retransmission. These two basic techniques have been combined into the Hybrid Automatic Repeat Request (HARQ), scheme where the unsuccessful attempts of retransmissions have been used in the FEC decoding and consequently the HARQ can be considered as another sort of link adaptation technique. Based on the channel quality the AMC selects the modulation and coding set for the data transmission and the HARQ uses the ACK/NACK information to determine the necessity of retransmission. These two link adaptation techniques have been reviewed and combined together in wireless transmission network to improve the network spectral efficiency and reduce the possible data transmission delay. Depending on the error-correcting capability of the truncated HARQ that depends on the maximum allowable number of retransmissions, the AMC is designed to guarantee the required system performance. In this report the basic AMC design is analyzed for truncated HARQ and several AMC design examples are discussed to illustrate the design principle.

2. System Model

In general a channel quality can be revealed by the received signal-to-noise ratio (SNR), γ. For flat fading channels, the Nakagami-m model is generally used to describe the γ statistically with a probability density function as: [1]

$$p_\gamma(\gamma)=\frac{m^m\gamma^{m-1}}{\bar{\gamma}^m\Gamma(m)}\exp\left(-\frac{m\gamma}{\bar{\gamma}}\right) \qquad (1)$$

where $\bar{\gamma}$ is defined as $\mathrm{E}\{\gamma\}$, the expected value of the received signal to noise ratio, and $\Gamma(m)=\int_0^\infty t^{m-1}e^{-t}dt$ is the Gamma function and m is the Nakagami fading parameter, $m \ge 1/2$. With m = 1, Eq. (1) reduces to

$$p_\gamma(\gamma)=\frac{1}{\bar{\gamma}}\exp\left(-\frac{\gamma}{\bar{\gamma}}\right) \qquad (2)$$

the probability density function of the signal-to-noise ratio for Rayleigh fading channel.

Assume for constant power transmission for the data sequence and let N denote the total number of modulation methods available and partition the entire SNR range into N+1 non-overlapping consecutive intervals, with boundary points denoted as $\{\gamma_n\}_{n=0}^{N+1}$ and,

$$\text{Modulation mode k is chosen when } \gamma \in [\gamma_k, \gamma_{k+1}) \qquad (3)$$

No data is transmitted when $\gamma_0 \le \gamma < \gamma_1$ for the modulation node n = 0 to avoid the deep fading channel environment. The main task for the AMC design is to find the boundary points $\{\gamma_n\}_{n=0}^{N+1}$. The boundary points $\{\gamma_n\}_{n=0}^{N+1}$ can be determined by approximating the packet error rate (PER) in the presence of white Gaussian noise (AWGN), as [2],

$$PER_n(\gamma) \approx \begin{cases} 1 & if\, 0 < \gamma < t_n, \\ a_n \exp(-g_n\gamma), & if \gamma \geq t_n, \end{cases} \tag{4}$$

where n is the modulation mode index (n = 1,2,….N), γ is the received SNR, and the mode dependent parameters a_n, g, t_n are obtained by fitting (4) to the exact PER [3].

The parameters a_n, g_n, t_n for five modulation modes, BPSK, QPSK, 16- QAM and 64-QAM with convolutional code with different coding rate for a packet length of 1080 bits, with generator polynomial of the mother code g = [133,171] have the following values [2],

	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
Modulation	BPSK	QPSK	QPSK	16-QAM	64-QAM
Coding rate	1/2	½	3/4	3/4	3/4
Date rate (bits/symbol)	0.50	1.00	1.50	3.00	4.50
a_n	274.7229	90.2514	67.6181	53.3987	35.3508
g_n	7.9932	3.4998	1.6883	0.3756	0.0090
t_n	-1.5331	1.0942	3.9722	10.2488	15.8754

If for a transmission follows a maximum number of retransmissions, $N_{\max}$, and assuming the Incremental Redundancy scheme in the HARQ scheme the boundary points $\{\gamma_n\}_{n=0}^{N+1}$ can also be determined by approximating the packet error rate (PER) in the presence of white Gaussian noise (AWGN), [4], as

$$PER_{n,i}(\gamma) \approx \begin{cases} 1 & if\, 0 < \gamma < t_{n,i}, \\ a_n \exp(-g_{n,i}\gamma), & if \quad \gamma \geq t_{n,i}, \end{cases} \tag{5}$$

where n again is the modulation mode index (*n = 1,2,….N*), γ is the received SNR and *i* is retransmission index ($i = 0,1,2,....N_{\max}$) with *i* = 0 is the initial transmission and a total of $N_{\max}$ retransmissions. The mode dependent parameters $a_{n,i}, g_{n,i}, t_{n,i}$ are obtained by fitting (5) to the exact PER [4]. With Rayleigh fading channel model and with two retransmissions the parameters $a_{n,i}, g_{n,i}, t_{n,i}$ are listed in the following table.

	Model 1	Model 2	Model 3	Model 4
Modulation	QPSK	QPSK	16-QAM	16-QAM
Code rate	1/2	2/3	1/2	2/3
Data rate (bits/symbol)	1	4/3	2	8/3
$a_{n,0}$	2.5	1.8	3.1	1.5
$a_{n,1}$	7.5	6.9	4.0	4.0
$a_{n,2}$	6.8	7.6	5.7	4.5
$g_{n,0}$	1.0	0.4	0.3	0.1
$g_{n,1}$	4.3	3.1	1.1	0.8
$g_{n,2}$	7.1	4.9	2.0	1.3

$t_{n,0}$	-0.3	1.8	5.7	6.2
$t_{n,1}$	-3.3	-2.0	1.0	2.4
$t_{n,2}$	-5.7	-3.9	-0.5	0.7

3. AMC Design Models

Conventional AMC Design without Retransmissions

In the conventional AMC design it requires the PER performance to be satisfied at the first transmission without considering the possibility of retransmissions i.e. it satisfies

$$PER_n(\gamma) \le PER_{target}$$

where PER_{target} is the target packet error rate then we have from Eq. (4),

$$PER_n(\gamma) \approx \begin{cases} 1 & if\, 0 < \gamma < t_n, \\ a_n \exp(-g_n\gamma), & if \gamma \ge t_n, \end{cases}$$

or

$$\gamma_n = \begin{cases} 0, & n = 0 \\ \frac{-1}{g_n}\ln(\frac{PER_{target}}{a_n}) & 0<n<N+1 \\ \infty & n = N+1 \end{cases}$$

or from Eq. (5) for retransmissions,

$$\gamma_n = \begin{cases} 0, & n = 0 \\ \frac{-1}{g_{n,0}}\ln(\frac{PER_{target}}{a_{n,0}}) & 0<n<N+1 \\ \infty & n = N+1 \end{cases}$$

AMC Design with the Same PER in All Transmissions

The packet error rate in the initial data transmission and later retransmissions has the same value and at the end of $N_{\max}$ retransmission the packet error rate satisfies the PER_{target}, i.e. for Eq. (4) we have $\{PER_n(\gamma)\}^{N_{\max}+1} \le PER_{target}$ assuming the channel characteristic keeps the same in all retransmissions, then the boundary SNR satisfies

$$\gamma_n = \begin{cases} 0, & n = 0 \\ \frac{-1}{g_n}\ln(\frac{PER_{target}^{\;1/(N_{\max}+1)}}{a_n}) & 0<n<N+1 \\ \infty & n = N+1 \end{cases}$$

or for Eq. (5),

$$\gamma_n = \begin{cases} 0, & n = 0 \\ \frac{-1}{g_{n,0}}\ln(\frac{PER_{target}^{\;1/(N_{\max}+1)}}{a_{n,0}}) & 0<n<N+1 \\ \infty & n = N+1 \end{cases}$$

In the above equations to find the boundary SNR points they have different values with different number of retransmissions $N_{\max}$.

AMC Design with Different PERs in Transmissions

The packet error rates have different values in the initial data transmission and later retransmissions but at the end of $N_{\max}$ retransmissions the packet error rate satisfies the PER_{target}. Assume the channel characteristic keeps the same during the $N_{\max}+1$ transmissions then in this situation it does not work for Eq. (4) but for Eq. (5) we have $\prod_{i=0}^{N_{\max}} PER_{n,i}(\gamma) \le PER_{t\arg et}$ and the boundary SNR becomes

$$\gamma_n = \begin{cases} 0, & n=0 \\ \dfrac{-1}{\sum_{i=0}^{N_{\max}} g_{n,i}} \ln\left(\dfrac{PER_{t\arg et}}{\prod^{N_{\max}} a_{n,i}}\right) & 0<n<N+1 \\ \infty & n=N+1 \end{cases}$$

AMC Design with Mixed PERs in Transmissions

In this situation it is the mixed of situations of Sections 3.2 and 3.3, it has some transmissions with the same PER but others with different PERs then the boundary SNR has the same expressions as in Section 3.3, with some of the $a_{n,i}$ will have the same value and also the $g_{n,i}$ will have the same value for those transmissions with the same PER.

4. System Performance

The probability of chosen modulation mode or index n has the closed form value as [1],

$$P_r(n) = \int_{\gamma_n}^{\gamma_{n+1}} p_\gamma(\gamma)d\gamma = \frac{\Gamma(m,\frac{m\gamma_n}{\bar{\gamma}}) - \Gamma(m,\frac{m\gamma_{n+1}}{\bar{\gamma}})}{\Gamma(m)}$$

The average PER corresponding to the *ith* transmission for modulation mode n can be calculated as

$$\overline{PER_{n,i}} = \int_{\gamma_n}^{\gamma_{n+1}} a_{n,i}\exp(-g_{n,i}\gamma)p_\gamma(\gamma)d\gamma = \frac{a_{n,i}}{\Gamma(m)}\left(\frac{m}{\bar{\gamma}}\right)^m - \quad \frac{\Gamma(m,b_n\gamma_n) - \Gamma(m,b_n\gamma_{n+1})}{(b_n)^m}$$

Where $b_n = \frac{m}{\bar{\gamma}} + g_{n,i}$ and $\Gamma(m,x) = \int_x^\infty t^{m-1}e^{-t}dt$ is the incomplete gamma function.

The average PER of the *ith* retransmission is then as the ratio of the average number of packets in error over the total average number of transmitted packets, i.e.

$$\overline{P_i} = \frac{\sum_{n=1}^{N} R_n \overline{PER_{n,i}}}{\sum_{n=1}^{N} R_n P_r(n)}$$, where R_n is the data rate in bits/symbol of modulation mode m. The average number of packet transmitted for each packet to be transmitted is:

$$\overline{N} = 1 + \sum_{i=0}^{N_{n\max}-1} \prod_{k=0}^{i} \overline{P_k}$$

And the overall average spectral efficiency is

$$R_{eff}(N_{\max}) = \frac{1}{N}\sum_{n=1}^{N} R_n P_r(n)$$

References

[1] M.S. Alouini and A. J. Goldsmith," Adaptive modulation over Nakagami fading channels," *Kluwer Journal on Wireless Communication,* vol. 13, no.1-2, pp.119-143, May 2000

[2] Q. Liu, S. Zhou and G. B. Giannakis," Cross-layer combining of queuing with adaptive modulation and coding over wireless links," *IEEE Military Communications Conference, MILCOM2003*, Vol. 1, pp. 712-722, 13-16 Oct. 2003

[3] Q. Liu, S. Zhou and G. B. Giannakis," Cross-layer combining of adaptive modulation and coding with truncated ARQ over wireless links," *IEEE Transactions on Wireless Communication*, Vol. 3, pp. 1746-1755, Sept. 2004

[4] S. H. Park, J.W. Kim and C. G. Kang," Design and adaptive and coding scheme for truncated HARQ," *2^{nd} International Symposium on Wireless Pervasive Computing, ISWPC 2007*, pp.151-155, 5-7 Feb. 2007

Proposed Text for "Link Adaptation Schemes"

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XX.X Link Adaptation Schemes

In the consideration of link adaptation schemes especially in the design of AMC with truncated HARQ it follows the following steps:

Step 0: For a communication channel, Determine or given the following design parameters:

N: Number of modulation schemes

N_{max}: Number of retransmissions

$PER_{t\arg et}$: Target packet error rate

m: Nakagami parameter

$\overline{\gamma}$: Average signal-to-noise ratio

$PER_{n,i}(\gamma)$: the measured or given packet error rate in each mode n and in the ith retransmission

Step 1: Determine the AMC model to be used

Step 2: Determine the coefficients for the PER in each modulation mode and each retransmission interval, $\{a_{n,i}, g_{n,i}, t_{n,i}\}$

Step 3: Determine the boundary signal-to-noise ratio in each modulation mode, $\{\gamma_n\}_{n=0}^{N+1}$ from $\{a_{n,i}, g_{n,i}, t_{n,i}\}$.

For frame-to-frame operation it operates,

Step 1: Update and determine the transmission mode for each frame form the signal-to-noise ratio γ

Step 2: Retransmit error packets by N_{max} retransmissions by using the parameter values $\{a_{n,i}, g_{n,i}, t_{n,i}\}$ in each retransmission

Step 3: Calculate the system spectral efficiency

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